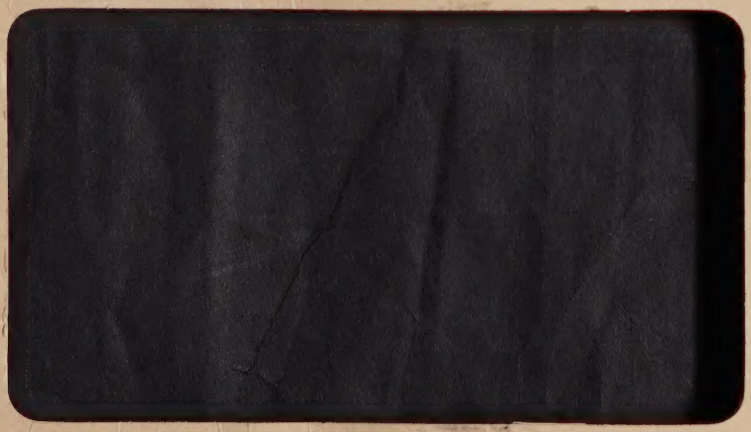
HARRIS SEMICONDUCTOR
AUG 27 '73

INSTRUCTION MANUAL



GENERAL RADIO

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WARRANTY

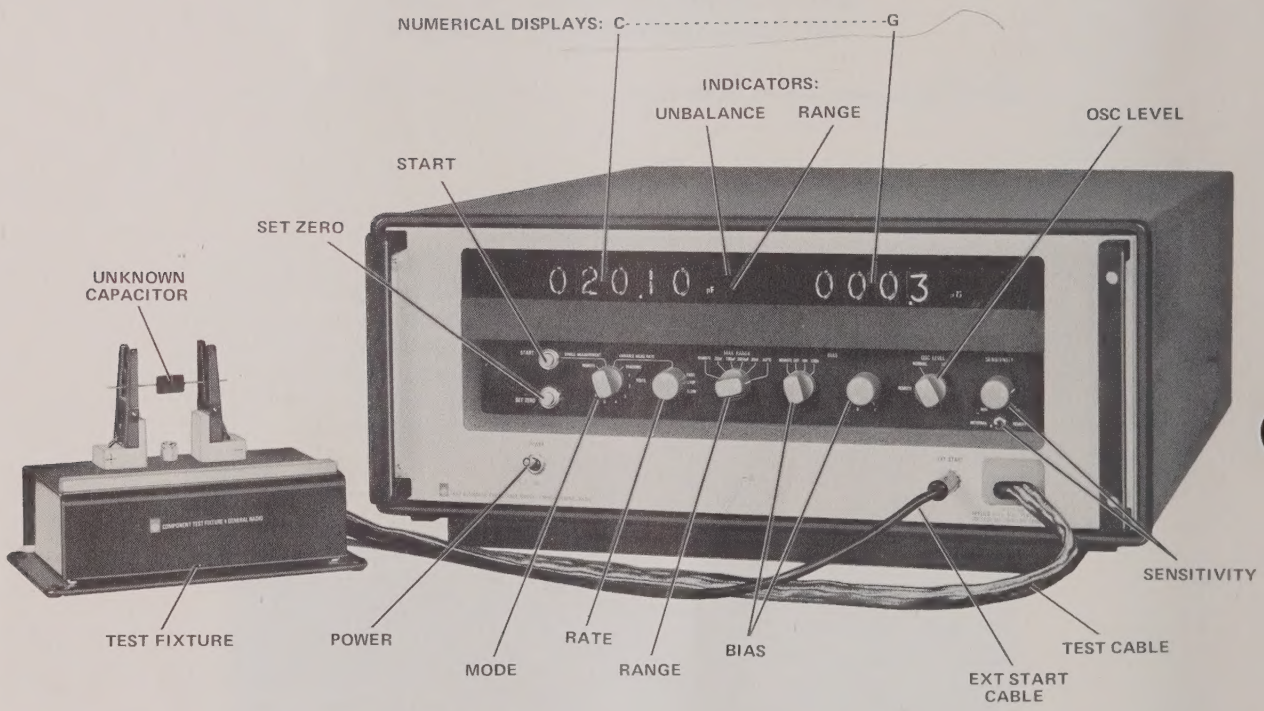
We warrant that each new instrument manufactured and sold by us is free from defects in material and workmanship and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, District Office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

Type 1682 Automatic Capacitance Bridge

C

©GENERAL RADIO COMPANY 1970

Concord, Massachusetts, U.S.A. 01742
Form 1682-0100-C
October, 1971
ID 4247



1682 Automatic Capacitance Bridge (1 MHz).

Condensed Operating Instructions

CAUTION

Be sure the line-voltage switch on the rear panel is properly set for the available power.

SETUP AND ZERO ADJUSTMENT.

a. Connect the 1682-P1 Test Fixture to the test cable, making sure that connectors marked A, B, C, D, and E are mated with their counterparts. Plug the external start cable (from the fixture) into the EXT START jack. Slide each pair of scissor-like terminals left or right to the center of the slot in which it moves. Insert a ½-in. length of bare wire between the blades of each terminal pair.

b. Set the bridge controls as follows:

Mode – TRACKING
RATE–SLOW
RANGE – 200 pF
BIAS – OFF (2nd control at any setting)
OSC LEVEL – NORMAL
SENSITIVITY – MAX (cw); switch to INTERNAL
A-S10 (rear) – down
POWER – on (up).

c. Press the SET ZERO button. Verify that numerical displays are zero, while the button is held in.

d. Adjust A-C24, using a screwdriver at rear panel, as follows: Turn the control just to zero readout, i.e., as far beyond the position of 00001-pF readout as would be required (turning the other way) to reach 00002 pF. Refer to paragraph 3.7 for supplementary procedures.

e. Change to the 20-pF range. Adjust A-C20 as in step d.

f. Change to the 2000-pF range. If necessary, adjust A-C23 as in step d. (For some early instruments with ID number 0100, this is an internal adjustment.)

g. Remove the wires from the terminals, but do not slide the terminal pairs left or right. (To do so would upset the zero adjustments.)

SINGLE-MEASUREMENT MODE.

a. Set the bridge controls as before except:

Mode – SINGLE MEASUREMENT
RANGE – AUTO

b. Insert a capacitor with clean leads into the test fixture.

c. Press the START bar on the test fixture or the START pushbutton. The bridge immediately makes a measurement, which remains displayed until you start another.

FIXED-RANGE AND BIASED CONDITIONS.

a. Set the RANGE switch to a fixed range. Press START. Notice that the RANGE light comes on if the unknown C (or G) is too large for the range. Conversely, if too small, resolution is lost by an unnecessary display of zeros. Fixed-range operation is useful for measuring a batch of similar capacitors; the set of data is easy to interpret.

b. Place a voltage-variable capacitor in the test fixture. Measure it several times with suitable bias levels chosen with the BIAS controls. The test fixture is labeled with the polarity. Do ***not*** use AUTO RANGE.

WARNING

Bias voltage appears at the test fixture. Take adequate precautions for operator safety. Also (for protection of the instrument) reduce bias to zero before changing RANGE.

c. Monitor the bias voltage with a high-impedance meter connected to EXTERNAL METER, a BNC jack on the rear panel.

FURTHER INFORMATION.

Refer to Sections 2 and 3 of this manual for details about:

1. TRACKING, and VMR modes.
2. Choice of OSC LEVEL.
3. Use of reduced SENSITIVITY
4. Data recording and programmability.

Specifications

Measurement	Range	*Accuracy (% of reading)
CAPACITANCE With concurrent loss measurement displayed as parallel conductance	00.001 to 1999.9 pF	0.2% ±.005% of FS
	02.00 to 19.99 nF	5% ±.05% of FS
CONDUCTANCE Concurrent with capacitance measurement	00.01 to 1999 μ℧	1% ±.05% of FS
	02.0 to 19.9 m℧	5% ±0.5% of FS

* Specified at the end of a 4-foot cable to unknown.

Display: 5-digit capacitance readout (4 digits on highest range, 0.001 to 20 nF) and 4-digit conductance readout (3 digits on highest range, 1 to 20 m℧); each with high-intensity neon readout tubes, decimal point, and unit-of-measurement. Display also indicates unbalanced condition.

Speed: Measurement rate is ≈ 20 measurements per second for ±10% of full-scale change in unknown, up to 50/s for closer tolerance unknowns, 6/s for full-scale change, and 2/s with range changes. Interval between measurements can be infinite (measurements initiated by front-panel pushbutton or external closure to ground) or from ≈ 1 to 0.02 s as set by front-panel control so that measurements are repetitive. A *tracking mode* provides continuous balances to monitor changing unknowns.

Terminals: Five-terminal connection that minimizes errors due to lead impedance and stray capacitance to ground are made by coaxial cables at the front of the instrument. A 1682-P1 Test Fixture is available for the rapid connection of axial-lead components and contains a start button to initiate the measurements. A 1682-P2 Text Fixture is available for the connection of GR900® connector-terminated components such as the GR 1405, 1406, and 1407 Coaxial Capacitance Standards. A 1682-P3 Test Fixture is available for the connection of GR 874®-connector-terminated components or, by means of a 777-Q3 Adaptor, to any component with ¾-in.-spaced binding posts. *Stray capacitance:* Up to 0.5 pF on lowest two ranges across the test fixtures can be cancelled by an adjustment on the rear of the 1682.

Ranges: Four. Ranging can be automatic, manual, or remote.

Oscillator Level: Voltage applied to unknown can be reduced from the normal 500 and 50 mV rms on the lower two ranges to 50 and 25 mV, with a 1-digit resolution loss, for special applications. Can also be factory modified, at additional cost, for a 1-V rms test voltage on lower two ranges (<200 pF) for conformance to MIL C55681.

Sensitivity: Can be manually or remotely reduced from maximum, with consequent loss of resolution, to overcome problems with nonlinear or rapidly changing unknowns, or external noise or hum pickup.

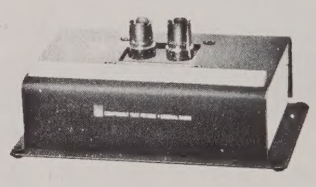
Bias: 0 to 100 V internal, source impedance 100kΩ, manually set; 200 V max external through 100 kΩ. A BNC connector is provided to monitor the level.

Interface: *Low-level Data Output,* 50-pin Amphenol Type 57 connector provides 10 digits of measurement data (5 for capacitance, 4 for conductance, 1 for range) plus various control inputs and outputs for systems use. Digits are 1-2-4-8-weighted BCD at standard TTL logic levels (logic "0" ≈ ground with 10-mA sink capability, logic "1" ≥ +3.5 V). *High-level Data Output,* same except all outputs are 15-V swing (logic "0" ≈ ground, with 10-mA sink capability, logic "1" ≈ +15V behind 12 kΩ). *Remote Programmability — Option 2,* 50-pin Amphenol Type 57 connector provides terminals for external remote programming of all control functions except line-voltage control. Functions are controlled by closures to ground or standard TTL or DTL signals (except bias and sensitivity by dc voltages).

Accessories Supplied: Power cord.

1682-P1 Test Fixture for axial-lead components

1682-P2 Test Fixture with GR900® terminals



1682-P3 Test Fixture with GR874® terminals

Accessories Available: 1682-P1, -P2, and -P3 Test Fixtures, printers, recorders, card-punch couplers, limit comparators.

Power: 100 to 125 and 200 to 250 V, 50-60 Hz, 60 W.

Mechanical: Bench or rack mount.

Dimensions (w x h x d): Bench, 19 x 7⅞ x 24¾ in. (485 x 200 x 630 mm); rack, 19 x 7 x 23⅛ in. (485 x 180 x 590 mm).

Description
1682 Automatic Capacitance Bridge (1 MHz)
Bench Model
Rack Model
Option 2 Remote Programmability, not available without option 5A or 5B
*Option 5A Low-Level Data Output
*Option 5B High-Level Data Output
1682-P1 Test Fixture, for axial leads
1682-P2 Test Fixture, GR900® terminals
1682-P3 Test Fixture, GR874® terminals

* Not available together in the same instrument.

See *General Radio Experimenter,* November/December 1969.

Introduction—Section 1

1.1 PURPOSE 1-1
1.2 DESCRIPTION 1-1
1.3 CONTROLS, INDICATORS, AND CONNECTORS 1-3
1.4 ACCESSORIES 1-3

1.1 PURPOSE.

The 1682 Automatic Capacitance Bridge is an accurate, fast, programmable, digital instrument for measuring capacitance and loss, as shunt conductance. Its range and accuracy are adequate for evaluation of virtually all capacitive devices below 20,000 pF. It is particularly useful for measurement of small, lossy capacitors, integrated circuits, and voltage-variable-capacitance diodes.

The test frequency of 1 MHz is well suited to the precise measurement of small capacitors, particularly those with appreciable losses. For that reason, agencies of the U.S. government often specify this frequency, as in the following MIL-C-specifications: 5D, 20D, 81B, 92B, 10950C, 11015D, 11272B, 14409B, 23269B, 38102/1B, 39001, 39014A, and 55187(EL).

Measurement rate is much faster than is possible with manually balanced bridges. For example a large number of capacitors within a ±10% range can be measured to ±0.2% accuracy at the rate of 20 per second if desired.

For high-volume production applications the 1682 bridge can be used as an integral part of automatic manufacturing equipment, the bridge providing fast, accurate measurements, so essential to efficient quality control. For automatic sorting, a 1781 Digital Limit Comparator will compare each bridge measurement against preset limits of C and G, making a GO or NO-GO decision.

For multipurpose installations, laboratories, and parts-inspection facilities, the 1682-P1 test fixture provides a convenient receptacle for a manual connection to the bridge. Capacitors can be inserted, measured, and removed as fast as an operator can handle them, i.e., up to about 2 per second.

Because the automatic component handler or manual test fixture is usually best located a few feet from a convenient location for the bridge, the 1682 is equipped with a 4-ft test cable. The bridge measures the C and G connected to the end of that cable.

Measurements are initiated in one of 3 modes, selected as desired:

1. Singly, by manual push button or remote signal.
2. Automatically, at a variable rate (1-50 per second).
3. By any change in value of the capacitor being tracked.

The range in use (20, 200, 2000 pF, or 20 nF) is selected in one of 3 ways:

1. Manually by front-panel switch.
2. Remotely.
3. Automatically, to suit the capacitor being measured.

Bias may be applied to the capacitor being measured, in one of 2 ways, and monitored with an external voltmeter:

1. Manually set, 0-100 V.
2. Remotely supplied, 0-200 V.

Multipoint connectors are provided for automatic programming of the bridge as well as coupling its measurement data and other information to auxilliary devices. Typically these include data printers, card or tape punchers, computers, comparators, component handlers, recorders, and special-purpose manufacturing equipment. Inquiries are invited for systems incorporating such devices.

1.2 DESCRIPTION. Figure 1-1.

The 1682 Automatic Capacitance Bridge is a fully automatic, essentially solid-state, 5-terminal, 1-MHz, programmable instrument. It is a true ratio-transformer bridge, with the basic accuracy of stable, passive, internal standards. There are several operating modes determining how measurements are initiated and a choice of 4 ranges as well

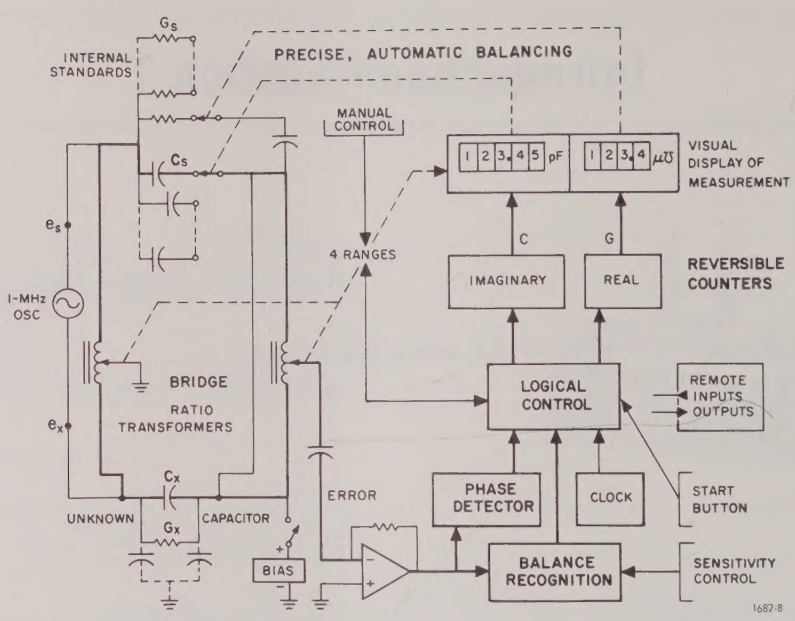


Figure 1-1. Simplified over-all diagram.

as automatic ranging. Oscillator level, sensitivity, and bias are controllable. Built-in test programs facilitate checkout and servicing.

The circuit is shown, quite simplified, in Figure 1-1. If the 200-pF range is selected, for example, the transformer ratios are 1:1, making $e_s = e_x$. Because the error amplifier has very low input impedance, the currents through standard and unknown legs of the bridge are proportional to their respective admittances. The error amplifier responds to the difference between these currents, a signal having real component proportional to $G_x - G_s$ and imaginary component proportional to $C_x - C_s$.

Logic circuits, responding to these error components, program reversible counters which step the internal standards C_s and G_s each in the the direction that reduces the error. Each counter also drives a numerical display, which on the 200-pF range indicates directly the value of the corresponding standard. When the error is small enough (the criteria depend on a SENSITIVITY setting) the logic circuits turn off the UNBALANCE indicator and stop the counting. The display is then the measured value of the unknown capacitor.

On the 20-pF range, the ratio transformers are connected so that e_x is 10 times e_s. Therefore, a 10-times-larger impedance of the unknown is balanced by the standards. The numerical-display decimal point is moved 1 place to the left, so that the display is again the measured value.

Other ranges use other decade settings of the ratio transformers, and appropriate corrections of the visual display. At balance it indicates in convenient, digital form, with decimal points and units, both measured capacitance and conductance.

If for any reason balance could not be achieved within 2 seconds, the measuring process would stop and an electrical "abort" signal would be generated. Then the display would include the final approximation to balance and — if that unbalance > 18 counts (20 counts = 0.1% full scale) — an UNBALANCE indication. If either parameter being measured, C_x or G_x, were too large for the selected range (or negative) a RANGE indication would also light up.

All displayed information, and more, is also presented electrically in binary-coded decimal form for use with printers and other data-handling equipment.

The 1682 is a 5-terminal bridge, for measuring ungrounded capacitors. As the diagram shows, each of the unknown-capacitor terminals is a junction for 2 bridge terminals, respectively "current" and "voltage." This structure enables the bridge to sense critical potentials through leads with a minimum of "IZ" drop, because they are separate from leads carrying most of the current. Therefore leads can be resonably long (for convenience) without degrading measurement accuracy. The 5th terminal is ground. Stray capacitances from either end of the unknown capacitor to ground have negligible effect on the measurement, even though they are as large as C_x. (If the 5th terminal were disconnected, these 2 strays each equal to C_x would affect the measured value by 50%.) See Figure 1-1.

The visual displays and all manual controls are located on the front panel. Connections may be made there to a switch which the operator can locate conveniently, to start

each single measurement. Data-output, programming, and bias connectors, as well as the power-line plug and fuses, are on the rear panel.

The test cable, which connects to a fixture holding the capacitor being measured is permanently attached at the lower right corner of the front panel.

Most of the small electrical parts are mounted on etched-circuit boards, of durable epoxy-glass-fiber sandwich construction. These can easily be replaced, if necessary, with a minimum of down time. To facilitate checking bridge performance and analysis of possible failures, front-panel-selected internal test programs have been provided as well as state-indicator lamps mounted directly on logic boards.

With a few exceptions the circuitry is solid state and most of the logic is handled by integrated circuits. Indicators and displays incorporate glow tubes and incandescent lamps. Reed switches serve where the series impedances of semiconductor switches would impair accuracy, i.e., to connect ratio transformers and the 5 largest standard capacitors.

1.3 CONTROLS, INDICATORS, AND CONNECTORS.

Tables 1-1 and 1-2 list and describe the front and rear panel controls, indicators, and connectors. Refer to the illustrations of Figures 1-2 and 1-3.

The TESTS function of the mode switch (17) is to make the bridge count in prescribed ways, for convenience in performance checkout. The speed of counting is controlled by the RATE control (16). The test routines are listed below:

1. ***C forward.*** The C counter counts up (until it reaches 19999) driving the C standard and corresponding numerical readout (item 2 in Figure 1-2) simultaneously.

2. ***C reverse.*** The C counter counts down (until it reaches 00000) as described above.

3. ***G forward.*** The G counter counts up (until it reaches 1999) driving the G standard and corresponding numerical readout (6) simultaneously.

4. ***G reverse.*** The G counter counts down (until it reaches 0000) as described above.

5. ***Balance.*** The bridge counts toward balance without time limit, as in the TRACKING mode, except that the counting rate is slower and depends on the RATE control. RANGE functions (15) are normal.

6. ***Spare.*** Unless another program is provided for the 6th test position, it is identical to the 5th.

1.4 ACCESSORIES.

Table 1-3 lists the most important accessories available for use with the 1682 Automatic Capacitance Bridge. A power cord is supplied with each instrument. Rack-mounting hardware is also supplied with "rack" instruments; for mounting refer to paragraph 2.5.

1.5 SYSTEMS APPLICATIONS. Figure 1-4.

The greatest capability of the 1682 Automatic Capacitance Bridge is found in a computer-controlled system where all measurements and data retrieval are performed under command of a program written expressly for one or more testing procedures. The computer can utilize and control a simple or complex system of automatic bridges, comparators, component handlers, bias supplies, environmental chambers, digital hygrometers, thermometers, and accelerometers, as well as graphical recorders, punched-card equipment, paper and magnetic tape recorders, etc.

There are many systems, with or without computers, and numerous combinations of equipment in which the speed and accuracy of the 1682 Bridge are of significant value. General Radio can supply systems and combinations to meet almost any requirement. Systems (generally) or combinations of equipment (on request) are completely assembled and checked as a unit before shipment.

Figure 1-4 represents a class of systems in which the 1682 Bridge performs a key role. Table 1-4 lists important accessory instruments.

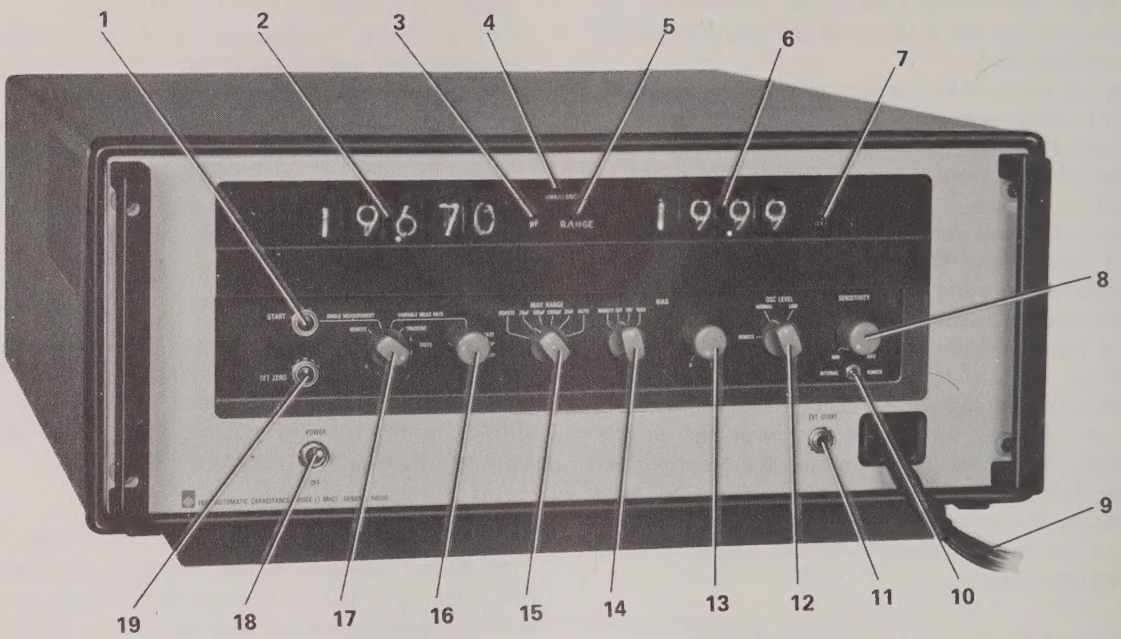


Figure 1-2. Front-panel controls, indicators, and connectors.

Table 1-1
FRONT CONTROLS, INDICATORS, AND CONNECTORS

Fig. 1-2 Item	Name	Description	Function
1	START button.	Push button.	Initiates a measurement when pushed. Appropriate to use in SINGLE MEASUREMENT mode, selected by item 17; see item 11.
2	Capacitance number readout.	Row of 5 numerical display tubes, with decimal points.	Displays capacitance measurement numerals and decimal point.
3	Capacitance units readout.	Set of 2 illuminated symbols: nF, pF.	Displays appropriate units to supplement item 2.
4	UNBALANCE indicator.	Illuminated word.	Indicates that bridge is unbalanced by more than 18 counts of the least significant C digit (plus the tolerance set by item 8).
5	RANGE indicator.	Illuminated word.	An "off-range" warning, indicates C_x or G_x is either negative or larger than the top of the selected range (top range if AUTO-selected). However, if the bridge is within 70 C counts of balance (0.35% of F.S.) this indicator will not light.

Table 1-1 (Cont)
FRONT CONTROLS, INDICATORS, AND CONNECTORS

Fig. 1-2 Item	Name	Description	Function
6	Conductance number readout.	Row of 4 numerical display tubes, with decimal points.	Displays conductance measurement numerals and decimal point.
7	Conductance units readout.	Set of 2 illuminated symbols: m℧, μ℧.	Displays appropriate units to supplement item 6.
8	SENSITIVITY control.	Stepless rotary pot, ends of range labeled: MIN, MAX.	Adjusts measurement precision. MIN: meas. completed when unbalance is 50 counts of least-significant C digit; MAX: same at 1 count. Item 10 overrides.
9	Test cable.	Special assembly of coaxial and other leads, with connectors, permanently attached to bridge.	Connects to test fixture at 4 ft. from instrument. NOTE: do not extend, shorten, untwist, or bend sharply.
10	Sensitivity switch.	Toggle switch, 2 positions: REMOTE, INTERNAL.	REMOTE: disables item 8 and substitutes remote control of sensitivity. INTERNAL: enables item 8.
11	EXT START jack.	Phone jack. Note: parallel circuit through item 1.	Initiates a measurement when circuit completed (through manual switch in 1682-P1 Test Fixture). Presence of any phone plug enables bias safety function (para. 3.8).
12	OSC LEVEL Switch.	Rotary switch, 3 positions: REMOTE, NORMAL, LOW.	REMOTE: enables remote control of oscillator level (normal or low). NORMAL: makes C_x voltage 500, 50 mV respectively on 20, 200-pF ranges. LOW: makes corresponding levels 50, 25 mV; also 5th digit of item 2 blank on all ranges and 4th digit of item 6 blank except for 2000-pF (2000-μ℧) range.
13	BIAS control.	Stepless rotary pot, ends of range labeled: 0, 1.	Sets bias on C_x in either range 0-10 V or 0-100 V selected by item 14. NOTE: Monitor item 5R.
14	BIAS switch.	Rotary switch, 4 positions: REMOTE, OFF, 10 V, 100 V.	REMOTE: applies external bias (item 3R) to C_x. OFF: no bias. 10 V: applies 10 V to item 13. 100 V: applies 100 V to 13. Note: Bias inhibited in AUTO RANGE.
15	RANGE switch.	Rotary switch, 6 positions: REMOTE, 20 pF, 200 pF, 2000 pF, 20 nF, AUTO.	REMOTE: enables remote control (5 choices). 4 mid positions: holds the indicated range. AUTO: enables the bridge to select range automatically.

Table 1-1 (Cont)
FRONT CONTROLS, INDICATORS, AND CONNECTORS

Fig. 1-2 Item	Name	Description	Function
16	RATE control.	Stepless rotary pot with detented position at ccw limit; range labeled: STOP (at detent), SLOW, FAST.	2 functions. (1) If item 17 at VMR, this controls rate of automatically starting new measurements. STOP: zero rate; SLOW: 1 meas/s; FAST: 50 meas/s. (2) If item 17 at any of TESTS, this controls counting rate (approx 1 to 1000 counts/s).
17	Mode switch.	Rotary switch, 10 positions: REMOTE, SINGLE MEASUREMENT, VARIABLE MEAS RATE, TRACKING, TESTS (1, 2, 3, 4, 5, 6).	REMOTE: enables remote control of all modes. S M: makes 1 meas. if started by item 1 or 11. V M R: makes meas. at rate set by 16. TRACKING: makes bridge count toward balance any time the unbalance exceeds level set by items 8 or 10. TESTS: makes bridge count slowly in explicit ways, for checkout and trouble analysis. Refer to paragraph 1.3 or Section 5.
18	POWER switch.	Toggle switch, down position: OFF.	Turns line power on and off.
19	SET ZERO button.	Push-button switch.	Resets both counters to zero as indicated by items 2, 6.

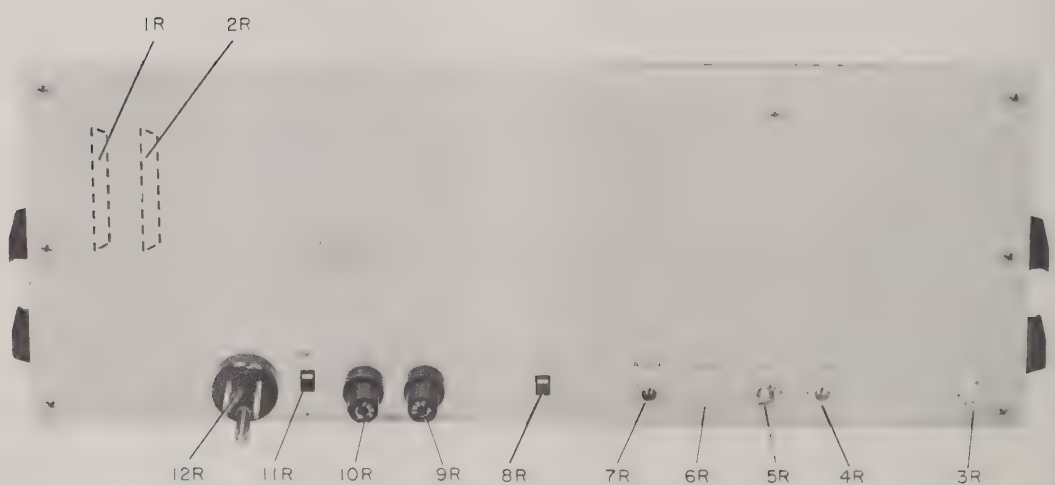


Figure 1-3. Rear-panel controls and connectors.

Table 1-2
REAR CONTROLS AND CONNECTORS

Fig. 1-3 Item	Name	Description	Function
1R	AUXILIARY connector.	50-pin socket. Note: supplied with Option 2 only.	Interfaces with other system components which remotely program the bridge, such as component handler, computer, test programmer, etc.
2R	DATA OUTPUT connector.	50-pin socket. Note: supplied with Option 5 only.	Interfaces with data-handling system components such as printer, comparator, component handler, card punch, D-A converter, computer, etc.
3R	BIAS VOLTAGE jack.	BNC jack.	Connects external bias source (±200 V limits) to unknown being measured, except on AUTO RANGE.
4R	A-C23 adjustment	Screwdriver adjustment (slotted end of shaft).	Compensates test-fixture capacitance on 2000-pF range. (Set so bridge reads zero with no capacitor in test fixture).
5R	A-C20 adjustment.	Screwdriver adjustment.	Same as item 4R, except for 20-pF range.
6R	EXTERNAL METER jack.	BNC jack.	Connects external meter or recorder, to monitor bias, internal or external (3R).
7R	A-C24 adjustment.	Screwdriver adjustment.	Same as item 4R, except for 200-pF range.
8R	A-S10	Slide switch, 2 positions: up, down.	Compensates test-fixture capacitance to supplement item 4R. **Up** for 1682-P2, 20-pF range. **Down** for other test fixtures and ranges.
9R	1-1/4 A FUSE. (fast acting)	Fuse in extractor-post holder.	Protection against damage from overload or short circuit.
10R	6/10 A FUSE. (slow acting)	Fuse in extractor-post holder.	Protection against damage from overload or or short circuit.
11R	Line-voltage switch.	Slide switch (labeled 50-60 Hz) 2 positions: 100 to 125 V, 200 to 250 V.	Accommodates power supply to either range of line voltages. (Paragraph 2.6.)
12R	Power plug.	3-pin power plug.	Connects to power line and earth ground.

Table 1-3
ACCESSORIES

Name	Description or Function	GR Part No.
Power cord.	No. 18, 3-wire cable.	4200-9622
Component test fixture	1682-P1. Holds axial-lead components for measurement.	1682-9601
Test fixture.*	1682-P2. Connects standards or unknown capacitors via single GR900® port.	1682-9602
Test fixture.	1682-P3. Connects standards or unknown capacitors via 2 GR874® ports for 3-terminal measurements.	1682-9603
Coaxial Capacitance Standards*	Type 1405 low-inductance coaxial standards, stable to <0.1% or .003 pF per yr. Listed in this order at right: 1, 2, 5, 10, 20 pF.	1405-9700 —through— 1405-9704
	Type 1406 low-inductance coaxial standards, stable to <.05%/yr. Listed in this order at right: 50, 100, 200, 500, 1000 pF	1406-9705 —through— 1406-9701
	Type 1407 low-inductance coaxial standards, stable to <.01%/yr. Listed in this order at right: .002, .005, .01 μF.	1407-9701 —through— 1407-9703
Component mount*	900-M coaxial mount. (Insert 0.1% resistors for conductance standards).	0900-9540
Cleaning kit	900-TOC. Solvent, brushes, and wipers, for cleaning coaxial connectors with Teflon** beads.	0900-9610
Extender boards	Allow instrument to be operated with one or more etched-circuit boards extended 4 or 5 inches for convenience in adjusting or servicing. 2 of 4215-2701 are required for the Z board.	4215-2700 (1 req'd) 4215-2701 (2 req'd)

*Recommended for checking bridge performance.
**Registered trademark of E.I. duPont de Nemours and Company.

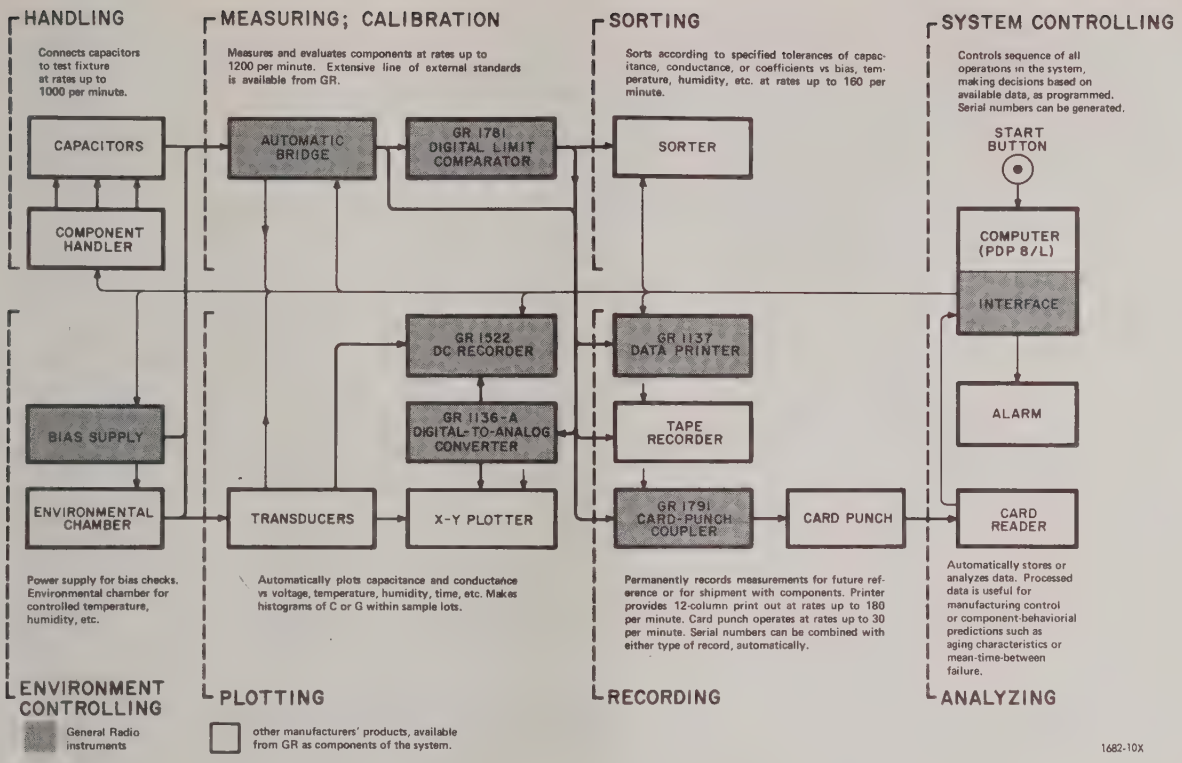

HANDLING
Connects capacitors to test fixture at rates up to 1000 per minute.
CAPACITORS
COMPONENT HANDLER
MEASURING; CALIBRATION
Measures and evaluates components at rates up to 1200 per minute. Extensive line of external standards is available from GR.
AUTOMATIC BRIDGE
GR 1781 DIGITAL LIMIT COMPARATOR
SORTING
Sorts according to specified tolerances of capacitance, conductance, or coefficients vs bias, temperature, humidity, etc. at rates up to 160 per minute.
SORTER
SYSTEM CONTROLLING
Controls sequence of all operations in the system, making decisions based on available data, as programmed. Serial numbers can be generated.
START BUTTON
COMPUTER (PDP 8/L)
INTERFACE
ALARM
GR 1522 DC RECORDER
GR 1137 DATA PRINTER
GR 1136-A DIGITAL-TO-ANALOG CONVERTER
TAPE RECORDER
BIAS SUPPLY
ENVIRONMENTAL CHAMBER
TRANSDUCERS
X-Y PLOTTER
GR 1791 CARD-PUNCH COUPLER
CARD PUNCH
CARD READER
Power supply for bias checks. Environmental chamber for controlled temperature, humidity, etc.
Automatically plots capacitance and conductance vs voltage, temperature, humidity, time, etc. Makes histograms of C or G within sample lots.
Permanently records measurements for future reference or for shipment with components. Printer provides 12-column print out at rates up to 180 per minute. Card punch operates at rates up to 30 per minute. Serial numbers can be combined with either type of record, automatically.
Automatically stores or analyzes data. Processed data is useful for manufacturing control or component-behavioral predictions such as aging characteristics or mean-time-between failure.
ENVIRONMENT CONTROLLING
PLOTTING
RECORDING
ANALYZING
General Radio instruments
other manufacturers' products, available from GR as components of the system.
1682-10X

Figure 1-4. A generalized system for automatic capacitance measurements at 1 MHz.

Table 1-4

ACCESSORY INSTRUMENTS AVAILABLE

Name	Description or Function	GR Part No.
Data Printer	Compact, economical machine for recording digital measurements. Accepts output of 1682, Option 5, directly. Capacity: 12 columns of digits. Rate: 3 lines/s max. Paper (tape) width: 2.25 in. Ink colors: black and red. (Red can be used whenever measurement is aborted.)	Type 1137
Card-Punch Coupler	Accepts parallel BCD data (up to 22 digits), converts data to serial-decimal form, provides buffered output to drive an IBM 526 Printing Summary Punch.	Type 1791
D-to-A Converter	Converts digital data to analog, suitable to drive a meter or recorder. Output is proportional to any 3 selected (consecutive) digits, or the last 2. (Storage circuitry in the converter accomodates either series or parallel time sequence of input data)	Type 1136

Table 1-4 (Cont)

ACCESSORY INSTRUMENTS AVAILABLE

Name	Description or Function	GR Part No.
Graphic Level Recorder	Makes a permanent record up to 4 in. wide, on a paper chart, of analog data such as 1682 bridge measurements converted by the 1136. Accuracy: ±1% of full scale; linearity: ±1% of full scale. Chart speeds: 75 in/min to 2.5 in./hr. Writing speeds: 1 to 20 in./s.	Type 1521-B
Dc Recorder	Programmable recorder. Makes a permanent record, up to 5 in. wide on a paper chart, of analog data such as 1682 bridge measurements converted by the 1136. Accuracy: ±0.5% of full scale; linearity ±0.25% of full scale. Chart speeds: 0.5 s/in. to 20 hr/in., without a change of gears or motor. Writing speeds: 0.5 to 65 in./s. Besides being programmable, the 1522 generates signals such as "chart is in the start position," "pen is within 0.5% of ideal position," "pen has reached a (preset) limit," or "chart paper has run out," which can be used even without a computer to program a measurement system. Chart-drive programmability makes X-Y recording feasible in computer-controlled system.	Type 1522
Digital Limit Comparator	Compares bridge measurement with 3 preset limits (max and min C, max G) for GO — NO-GO testing. Visual display of reason for NO-GO. Output circuit actuates automatic equipment such as component handler. Several comparators may be combined in a component-sorting system.	Type 1781
Digital Limit Comparator	Similar to the Type 1781; has 4 limits (max and min C, max and min G), visual displays, and output circuit.	Type 1783
Bias Power Supply	Voltages: 0-50 V in 0.1-V steps. Control: manual or programmed. Current: −10 to +40 mA rating; instant limiting at 100 mA, max.	2995-8158

Installation—Section 2

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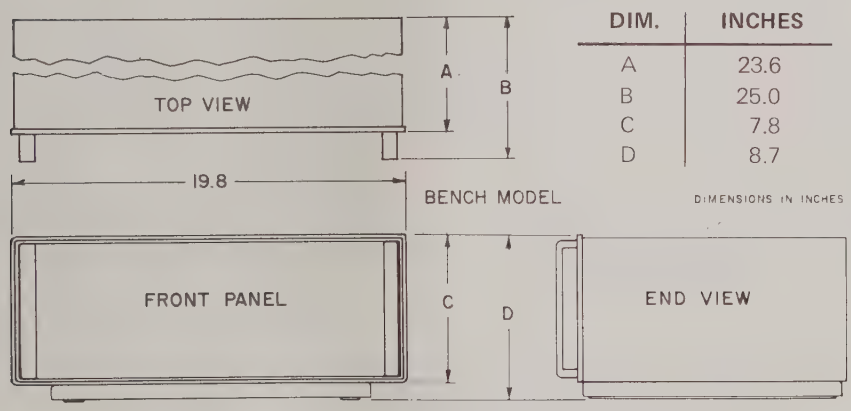
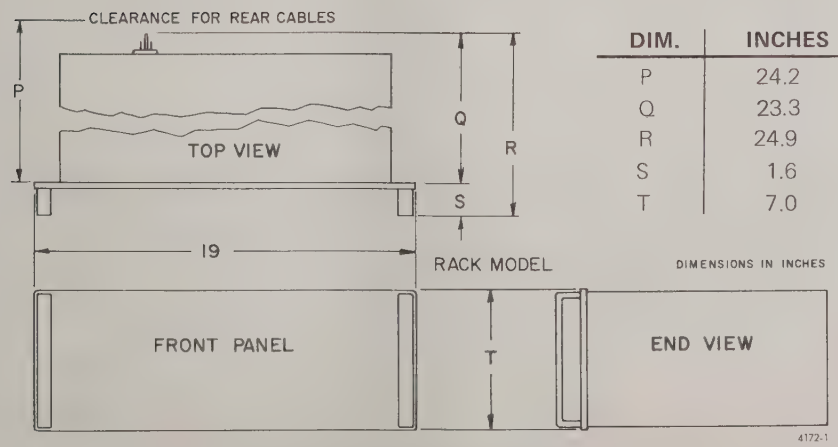


DIM.	INCHES
A	23.6
B	25.0
C	7.8
D	8.7

Figure 2-1. Dimensions of the bench-model instrument.



DIM.	INCHES
P	24.2
Q	23.3
R	24.9
S	1.6
T	7.0

Figure 2-2. Dimensions of the rack-model instrument.

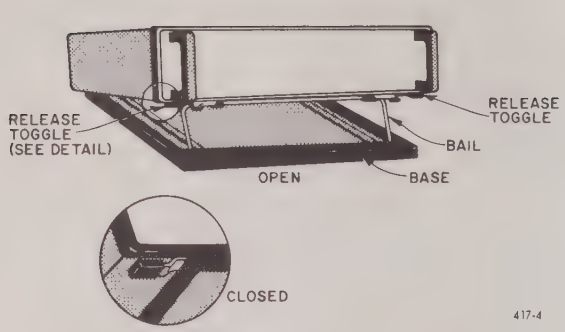


Figure 2-3. The instrument may be tilted for a higher viewpoint.

2.1 GENERAL.

The 1682 Automatic Capacitance Bridge is available for either bench use or for installation in an EIA Standard RS-310 19-in. relay rack with universal hole spacing. Appropriate cabinet and hardware sets are available for conversion of a bench model for rack installation or vice versa.

Locate the instrument for convenience of operation and in a suitable environment. Avoid blocking the flow of air through the vents. The test cable (leading to the test fixture holding the capacitor being measured) is permanently installed at the front panel.

2.2 DIMENSIONS.

The dimensions of bench and relay-rack models of the instrument are given in Figures 2-1 and 2-2.

2.3 ENVIRONMENT.

The instrument is designed to operate in rooms where people work. Its specifications are valid over a temperature range of 0-50° C. Storage temperature range is −20 to +70° C.

It is important to keep vents unobstructed, for normal air convection. The environment of the instrument is directly affected by others nearby, particularly those below if they are hot.

2.4 BENCH MODELS.

2.4.1 Position, Horizontal or Tilted. Figure 2-3.

Each bench model comes completely assembled in a metal cabinet intended for use on a table or laboratory bench. If the user's viewpoint is much above bench level, he may prefer to tilt the instrument for a better view of front-panel legends and indicators. The base remains horizontal. Use the following procedure for tilting:

a. Reach under the cabinet, near the front, at each side of the pedestal base, and push each release toggle back. (It moves about ¾ in.)

b. Lift the front of the instrument a few inches from its base, keeping each hand where a fingertip can touch the bail as it swings down.

c. Swing the bail forward while raising the instrument, then lowering it gently to rest on the bail. This is the tilted, or open position.

d. To reverse the procedure, first be sure the release toggles are pushed back.

e. Lift the cabinet slightly, as before; swing the bail back; then lower the cabinet fully.

f. Lock the cabinet and base together by sliding the release toggles forward. This is the horizontal, or closed position.

2.4.2 Cabinet Removal. Figure 2-4.

To remove the bench-model cabinet, first set the instrument in the horizontal position, free of unnecessary cables, and proceed as follows:

a. Remove the 4 dress-panel screws (A) accessible through holes in the handles.

b. With caution not to let the instrument drop out of its cabinet, turn them face down to rest on the handles.

c. Pull the cabinet up and off. Carefully return the instrument to a horizontal position.

2.4.3 Conversion for Rack Mounting.

To convert a bench instrument for rack mounting, exchange the cabinet and install appropriate hardware, as follows:

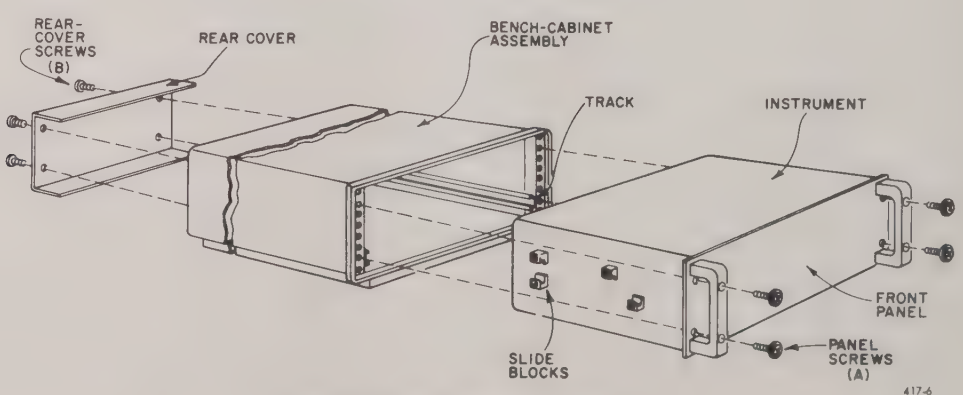


Figure 2-4. Bench-cabinet installation.

a. Obtain a Rack-Mounting Cabinet Kit 4174-3744 (Table 2-1) from General Radio Company.

b. Obtain, optionally, Bracket Set 4174-2000 (Table 2-2). This is especially recommended for a heavy instrument, which needs support from the rear rail of the rack.

Table 2-1
RACK-MOUNTING CABINET KIT 4174-3744

Quantity	Description	Part No.
1	Cabinet assembly, including:	
	2 Covers.	4174-8422
	2 Side pans.	4174-8674
	24 Eyelets, used as rivets.	—
	1 Set of 2 tracks with 4 rivets.	4174-2407
1	Hardware set, including:	4174-2002
	4 Screws, 8-32, 1/4 in, thread forming ("B" for rear cover).	—.
	4 Screws, 10-32, 9/16 in, dress ("A" for front panel).	—
	4 Sets of 10-32 nuts and washers (for screws "A", if needed).	—

Table 2-2
BRACKET SET 4174-2007

Fig. 2-5 Ref.	Quantity	Description
D	2	L brackets with elongated holes.
E	4	Screws, 8-32, 3/16 in., thread forming.
C, F	8	Screws, 10-32, 1/2 in., thread forming.

c. Remove the cabinet, as in paragraph 2.4.2.

d. Remove the rear cover from the bench cabinet, with screws (B, Figure 2-4), for later installation on the rack cabinet.

e. Proceed with the rack installation; skip to paragraph 2.5.2, step b.

2.5 RACK MODELS.

2.5.1 General.

Each rack model comes completely assembled in a suitable metal cabinet, which is designed to stay semi-permanently in a rack. The instrument can be drawn forward on extending tracks for access with support, or (with a lift) withdrawn completely. The cabinet and hardware listed in Tables 2-1 and 2-2 are all included with a rack-model instrument.

2.5.2 Installation. Figure 2-5.

Directions follow for mounting the cabinet in a rack and installing the instrument on its tracks:

a. Remove 4 dress-panel screws (A) and slide the instrument out of the cabinet. When free motion along the tracks is stopped, tilt the front of the instrument up slightly. Continue withdrawal, past the stops, pulling the instrument horizontally until it is free.

b. Insert the rack cabinet wherever desired in the rack — be sure it's level — and fasten it with 4 screws (C) to the front rails.

c. If the cabinet can be supported at the rear (Figure 2-5) remove the rear cover (screws "B") for better access. Otherwise skip to step e.

d. Use brackets (D) to support the cabinet with the rear rails. Generously elongated screw holes allow positioning as desired. With screws (E) fasten brackets to cabinet. Pass screws (F) through brackets and screw them into the rear rail. (Details may be varied to suit particular situations.)

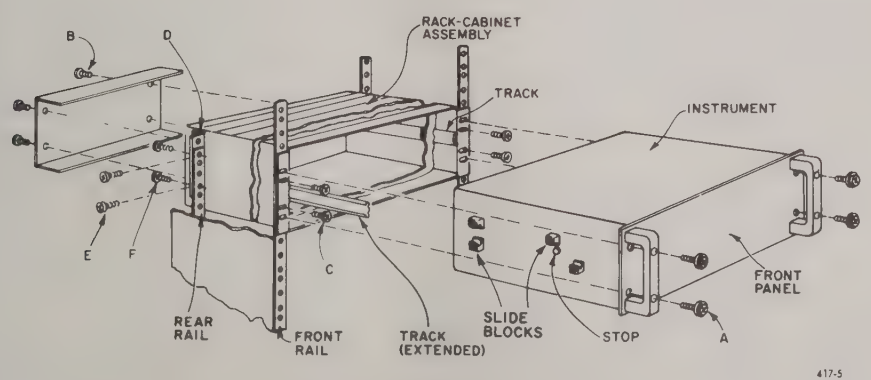


Figure 2-5. Rack-cabinet installation.

Table 2-3
BENCH CABINET KIT 4173-4004

Quantity	Description	Part No.
1	Bench Cabinet Assembly, including:	4173-3844
	1 Cabinet	4173-1684
	1 Gasket	5331-2182
	2 Filters	5270-3509
	1 Base with hardware (includes hinge, bail, and toggles)	4171-2127
	Factory assembled with:	
2	Tracks	4171-8607
2	Brackets, rear, (and screws)	4171-8804
	Supplied with:	
4	Screws, 8-32, 1/4 in., thread forming ("B" for rear cover)	—
4	Screws, 10-32, 9/16 in., dress ("A" for front panel)	—

e. To install the instrument, first set its rear edge into the cabinet front opening. Slide the instrument back, making sure that the rear slide blocks and the upper front ones engage the tracks. (Stops prevent further insertion.)

f. Slide the instrument forward ***with*** the tracks, keeping a hand on each side (fingers underneath). Slide the instrument ***back*** about ½ inch along both tracks, past the stops, by pressing down on the tracks (with thumbs) while tilting the front of the instrument up slightly.

g. Push the instrument back into the rack, checking for smooth operation of the tracks and slide blocks.

NOTE

The instrument is now readily accessible for behind-the-panel adjustments. It slides in and out freely on extending tracks. Obtain this advantage whenever desired by removing the panel screws (A).

h. Fasten the instrument in place using 4 dress-panel screws (A). (Pass the screwdriver through holes in the handles.)

i. Replace the rear cover, with its screws (B).

2.5.3 Conversion to Bench Use.

To convert a rack-mounting instrument for bench use, exchange the cabinet, as follows:

a. Obtain a Bench Cabinet Kit 4173-4004 (Table 2-3) from General Radio Company.

b. Remove the instrument from the rack cabinet, after removing the panel screws (A, Figure 2-5). (When free motion along the tracks is stopped, tilt the front of the instrument up slightly to clear the stops.)

c. Stand the instrument face down, to rest on its handles, and slip the bench cabinet over it. Carefully return it to a horizontal position.

d. Fasten instrument to cabinet using dress-panel screws (A, Figure 2-4).

e. Transfer the rear cover, with screws (B), from rack cabinet to bench cabinet.

2.6 POWER-LINE CONNECTION.

Power requirement is 60 W at 100 to 125 or 200 to 250 V, 50 to 60 Hz. Make connections as follows:

a. Set the line-voltage switch on the rear panel (Figure 1-3) to correspond with the available power-line voltage. Use a small screwdriver to slide the switch.

b. Connect the external power line to the power plug using the power cord supplied (Table 1-3) or an equivalent, 3-conductor cord.

Fuse A-F50, 1.25A protects the lower-line-voltage circuit; fuse A-F51, 0.6A protects the higher.

2.7 LINE-VOLTAGE REGULATION.

The accuracy of measurements accomplished with precision electronic test equipment operated from ac line sources can often be seriously degraded by fluctuations in primary input power. Line-voltage variations of ±15% are

commonly encountered, even in laboratory environments. Although most modern electronic instruments incorporate some degree of regulation, possible power-source problems should be considered for every instrumentation setup. The use of line-voltage regulators between power lines and the test equipment is recommended as the only sure way to rule out the effects on measurement data of variations in line voltage.

The General Radio Type 1591 Variac® Automatic Voltage Regulator is a compact and inexpensive equipment capable of holding ac line voltage within 0.2% accuracy for input ranges of ±13%. It will assure, for example, that an instrument rated for 100-125 (or 200-250) V can be operated reliably in spite of varying input voltages in the range 85-135 (or 170-270) V. The 1 kVA capacity of the 1591 will handle a rack full of solid-state instrumentation with no distortion of the input waveform. This rugged electromechanical regulator comes in bench or rack-mount versions, each with sockets for standard 2- or 3-wire instrument power cords.

Further details can be found in your GR catalog or in the *GR Experimenter* for October, 1967.

Table 2-4
BINARY-CODED DECIMALS (BCD)

Signal Weight (Binary) 8	4	2	1	Digit (Decimal)
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9

2.8 SYSTEM CONNECTIONS.

2.8.1 Data-Output Connector. Figures 2-6, 2-7.

Make connection from the DATA OUTPUT socket on the rear of any 1682 Option 5 bridge using a 50-pin plug, Amphenol P/N 57-10500-7 and cable suited to the system. For pin identification, refer ahead to Figure 2-7.

Option 5 provides data for printers, comparators, card-punch couplers, etc. It also responds to 2 remote-control commands, both affecting measurement ***start***. Use this capability to synchronize bridge measurements with other (generally slower) instruments or machines. There are 2 versions of Option 5, as follows.

Option 5A provides low-level data-output signals, at standard TTL logic levels. Logical "1" is a +5 V source, "0" is a 10-mA sink. Option 5B provides high-level data-output signals. Logical "1" is a +15 V source, "0" is a 10 mA sink. For more details, refer ahead to Table 2-8.

The primary output data, C and G, are available in binary-coded decimal form, the code being "1-2-4-8" as detailed in Table 2-4. A typical digit is conveyed by the data on pins 5, 6, 30, and 31 at the right in Figure 2-7. This example is the least significant digit of the G data. If that digit is 7, pins 5, 6, and 30 are each "1", pin 31, "0".

The range outputs determine the decimal factors associated with C and G data. For example, if the printer is connected to write range as a decimal number to the right of C and G values (decoding "range" as another digit of data) the printed output looks like the right side of Table 2-5. (Of course, a more convenient print-out would incorporate a decimal point located in the pattern of the first 3 ranges of visual display; however, that pattern may not be feasible with ordinary printers.)

$\overline{START}$/S. This input is usually used with the mode switch set to SINGLE MEASUREMENT. Each digital command starts a new measurement if the signal:

1. Has a duration of 20 μs min.
2. Follows the previous start by 75 ms min.
3. If ac coupled, has amplitude = 3 V pk-pk min.
4. If dc coupled, crosses the threshold level.
5. Is a transition in the proper sense.

Table 2-5
INTERPRETATION OF DATA PRINT-OUT

Range	Visual Display on Bridge		Print-out		
20 pF	12.345 pF	12.34 μ℧	12345	1234	0
200 pF	123.45 pF	123.4 μ℧	12345	1234	1
2000 pF	1234.5 pF	1234. μ℧	12345	1234	2
20 nF	12.34 nF	12.3 m℧	12345	1234	3

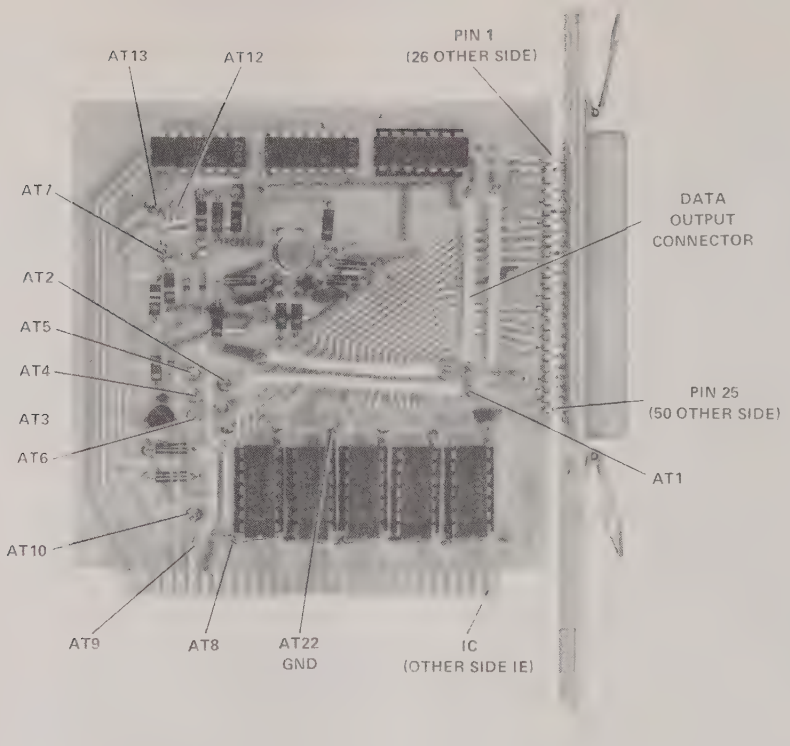


Figure 2-6. N-Board assembly, showing terminals and jumpers in the START/S and INHIBIT circuits. (Option 2 bridges only.)

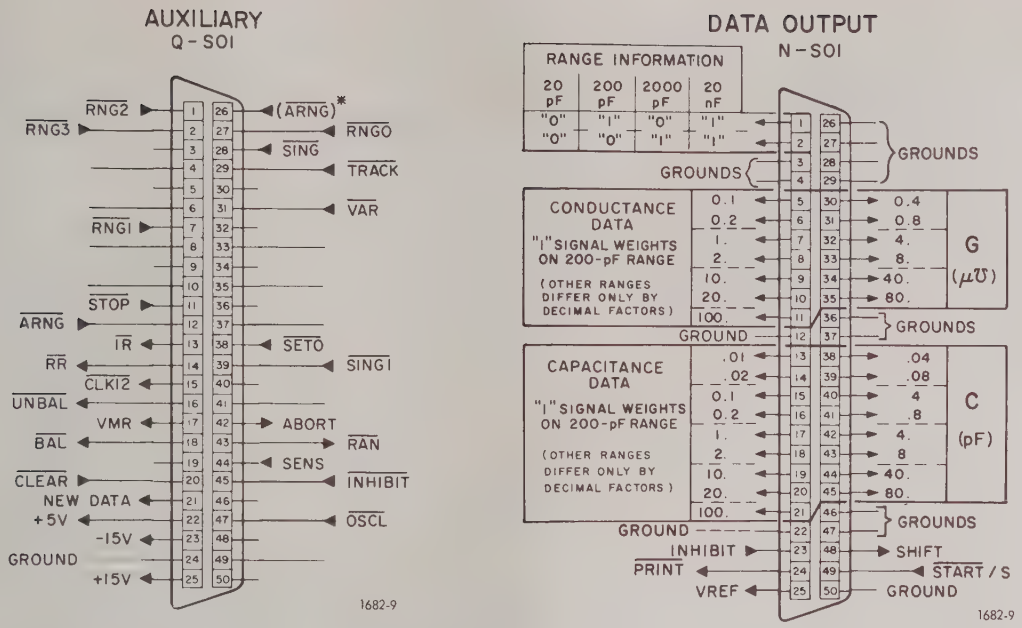
Table 2-6

N-BOARD WIRING FOR "$\overline{\text{START}}$/S" INTERFACE ADAPTIONS

Signal Source	Coupling	Trigger Sense	Trigger Level	Jumper between Terminals: AT2 to	AT3 to	Also:
Switch	to gnd	closing	—	AT4	5.6 kΩ	12 kΩ Δ
-or-					AT1 Δ	AT3-10
DTL ckt	dc	"1-0"	+0.4 V	same*	same*	same*
Switch	to gnd	opening	—	5.6 kΩ	AT4	12 kΩ Δ
-or-				AT1 Δ		AT2-10
DTL ckt	dc	"0-1"	+2.4 V	same	same	same
Voltage	dc	+ going	+5.0 V	AT1	AT4	none
			+1.5	1	5	(Remove
			−5.0	1	6	resistor
						jumpers.)
		− going	+5.0 V	AT4	AT1	
			+1.5	5	1	
			−5.0	6	1	
	ac	+ going	—	AT1	AT4	
		− going	—	6	1	

* Original connections, as manufactured.

Δ Use indicated resistor as a jumper, not a direct connection.



*$\overline{\text{ARNG}}$ is connected at pin 26 in early versions, ID 0100; at pin 12 in later instruments.

Figure 2-7. Terminal identifications at rear-panel connectors, exterior view. DATA OUTPUT on Option 5, AUXILIARY on Option 2 bridges. Arrow toward connector = input; away = output.

Either sense (0-1 or 1-0) may be chosen, and threshold levels of +5, +1.5, or –5 V selected, by making the appropriate soldered connections on the N-board. In the same way, the circuit may be made responsive to switch closures to ground. Proceed as follows:

a. Remove 2 screws holding the plate labeled DATA OUTPUT on the rear panel.

b. Slide the plate and connector as a unit upwards to disengage the attached N-board from an internal connector.

c. Lift the assembly out of the instrument to the rear.

d. Refer to Table 2-6 for the appropriate jumper positions, to Figure 2-6 for terminal locations.

e. Make the changes required, if any.

f. Reassemble the N-board in the instrument.

g. If the system is to be changed again, tag the bridge with a note on the present N-board jumper pattern.

INHIBIT. This input is used with the mode switch set to VARIABLE MEAS RATE. "1" prevents initiation of new measurement; "0" enables measurements at the manually chosen RATE. If a start has been inhibited by this function, the next measurement begins 1-1000 ms after the "1" to "0" transition; the delay time depends on the RATE setting.

Switch closure to ground will not drive the INHIBIT input unless a minor change is made. Following the procedure given under $\overline{\text{START}}$/S, above, change the jumper from the AT 7-13 position (as supplied) to 7-12. Now, closure to ground is "0" and open circuit is "1"

NOTE

If this change is made in the N-board wiring, the bridge requires the following procedure before it is suited to general-purpose applications. Provide INHIBIT with a "0" signal or *ground pin 23 of DATA OUTPUT* to enable rear-connector remote start functions (SINGLE MEASUREMENT mode) or normal repetitive starts (VARIABLE-MEAS-RATE mode).

2.8.2 Auxiliary Connector. Figure 2-7.

Make connection from the AUXILIARY socket on the rear of a 1682 Option 2 bridge using a 50-pin plug, Amphenol P/N 57-10500-7 and cable suited to the system. For pin identification, refer to the figure. Label the connector clearly, to distinguish it from the physically similar one used for DATA OUTPUT.

The full set of system functions characteristic of a 1682, Options 2 and 5, Automatic Capacitance Bridge is presented in Figure 2-7 and Table 2-7, with sufficient detail for most system planning. In general, all the digital inputs and outputs are buffered by TTL logic circuits. All digital inputs at the AUXILIARY connector have "pull-up circuits" so that each is in "1" state if open-circuited, "0" if grounded.

Table 2-7
PROGRAMMING FUNCTIONS

DATA OUTPUT connector

Pin No.	Signal	Function
23	INHIBIT	"1" prevents initiation of new measurement in SM or VMR modes; inhibits SING1, START/S, and ZSTART. Cannot inhibit counting in any TEST mode (See INHIBIT.)
24	PRINT	"0" = print command, when bridge has reached balance (or aborted the measurement). "1" = measurement in process. ("1" holds for 100 μs after balance is reached.)
25	VREF	DC reference potential at nominal "1" (+5 V for Option 5A, +15 V for 5B). Current rating = 100 mA max.
48	SHIFT	"1" = abortion (holds from abort decision to initiation of next measurement). "0" = normal. Use to shift color of print-out.
49	START/S	Starts measurement. Use in SINGLE-MEAS mode (which may be remotely selected). Jumpers on N-board determine required sense and ac/dc coupling. Min interval between commands: 75 ms (anti-bounce circuit). Min duration of start command: 20 μs.

AUXILIARY connector

Pin No.	Signal	Function
27	RNG0	"0" selects 20-pF range
7	RNG1	"0" selects 200-pF range
1	RNG2	"0" selects 2000-pF range
2	RNG3	"0" selects 20-nF range
		(if RANGE switch reads REMOTE *and* ARNG is "1". (3 of these 4 signals must be "1".)
11	STOP	"0" arrests counters temporarily; "1" permits operation. (The 2-sec period to abortion is not lengthened by "0".)
12	ARNG	"0" selects autoranging; "1" enables remote range selection (RNG-series). Valid only if RANGE switch set to REMOTE
13	IR	"0" indicates C_x < C-readout (imaginary counter reversed). "1" = the converse.
14	RR	"0" indicates G_x < G-readout (real counter reversed). "1" = the converse.
15	CLK12	Bridge main clock signal (inverted), a rectangular wave at counting rate (6 or 400 kHz, except in TEST modes 1-1000 Hz set by variable-rate control). Count advances just after "0-1" transition.
16	UNBAL	"0" indicates unbalance more than 18 "C" counts (0.1% of full range) above level set by SENSITIVITY control

AUXILIARY connector (cont)

Pin No.	Signal	Function
17	VMR	Variable-measurement-rate generator output. In VMR mode, if there is no inhibit command, new measurement starts automatically at "1-0" transition, but that is not permitted until after balance is recognized (see PBUSY, Table 6-1).
18	BAL	"0" = measurement completed by balance or abortion. "1" = unbalance more than 1 count (.005% of full range) away from reference set by SENSITIVITY control; no abortion.
20	CLEAR	"0" (externally applied) resets a flip-flop, making NEWDATA = "0".
21	NEWDATA	If reset as above, holds "0" until 100 μs after completion of measurement. "1" transition indicates new data ready.
28	SING	"0" = SINGLE-MEAS
29	TRACK	"0" = TRACKING
31	VAR	"0" = VAR-MEAS-RATE
		(modes if mode switch set to REMOTE. (2 of these 3 must be "1"; if all 3 are "1", SING-MEAS mode is selected.)
38	SETO	"0" sets both counters (also C and G standards and numerical readouts) to zero.
39	SING1	"1-0" transition initiates measurement (unless INHIBIT = "0" or INHIBIT = "1"). Use in single-measurement mode. Max rep rate = 50 Hz. Use pulse source or a-c coupling to limit "0" to 20 ms max duration. (Min duration 2 μs.)
42	ABORT	"0-1" transition indicates measurement aborted, "1" is held until initiation of next measurement.
43	RAN	"0" = indication that bridge cannot balance on the selected range; C_x or G_x is either negative or too large. If RAN = 0 and unbalance is greater than 70 counts (0.35% of full C range) the RANGE indicator will light up
44	SENS	Analog voltage replaces SENSITIVITY control when corresponding switch at REMOTE. Max sens at +7 mV, min = +5 V. Linear range corresponds to 1–50 counts of least significant C digit.
45	INHIBIT	"0" prevents initiation of new measurement in SM or VMR modes; inhibits SING1, START/S, and ZSTART. Cannot inhibit counting in any TEST mode (See INHIBIT.)
47	OSCL	"0" = low, "1" = normal (equivalent to LOW and NORMAL selections by OSC LEVEL control) if that control set to REMOTE. (However, OSCL does not affect numerical display as the manual control does.)

Table 2-8
INTERFACE REQUIREMENTS FOR DIGITAL SYSTEMS

Connector	1682 Option	Direction	Characteristics of Bridge	Requirements of External Circuit
AUXILIARY	2	Output	Standard DTL integrated-ckt output. "1": +5.0V behind approx 6 kΩ (+3.1 V min at terminal when load current is 0.18 mA). "0": semi-conductor switch closed to ground (+0.4 V max at terminal while accepting 13.5 mA from + ext source).	Response to signals described at left. [Ext ckt may be active; if so, must be limited to open-ckt voltage in range –4 to +8 V, short-ckt current = 10 mA max (+ voltage) or 1 mA max (– voltage.)]
		Input	Standard DTL integrated-ckt input; has additional "pullup" resistor, 5.6 kΩ. (Bridge ckt an active load, equiv to 5.6 kΩ returned to +5.0 V when driven to "1", 2.5 kΩ to 5.0 V for "0".)	Capability to drive bridge terminal to: "1": +2.4 to +5.5 V (an open ckt will do); "0": 0 to +0.4 V with sink capability = 2.2 mA. Use DTL output or a switch connecting to ground.
DATA OUTPUT	5A	Output (low level)	Standard TTL integrated-ckt output. "1": +5.0 V behind a nonlinear ckt (+2.9 V min at terminal when load current is 1.3 mA). "0": semiconductor switch closed to ground (+0.4 V max at terminal while accepting 15 mA from + ext source).	Response to signals described at left. (Ext ckt may be active, having the characteristics given above for Option 2 outputs.)
		Input	$\overline{\text{START}}$/S: Bridge input is equiv to 11 kΩ returned to +6.8 V (unless jumpers are changed).*	Capability to drive bridge terminal to: "1": +4 V to +50 V (an open ckt will do); "0": 0 to +0.4 V with sink capability = 1 mA. Use a DTL output or a switch closure to gnd.*
			INHIBIT: Bridge input is equiv to 15 kΩ returned to –15 V when driven to "1", 9 kΩ returned to –2 V when "0" (unless jumpers are changed).*	Capability to drive bridge terminal to: "1": +2.4 to +15 V (2 mA req'd at +15 V); "0": –2.4 to +0.4 V Use DTL output or switch closure to + voltage. (For switch closure to gnd, see note.)*
	5B	Output (high level)	High-level DTL integrated-ckt output. "1": +15 V behind approx 12 kΩ. (+13 V min at terminal when load current is 0.1 mA). "0": semiconductor switch closed to ground (0.5 max at terminal while accepting 10 mA from + ext source).	Response to signals listed at left. [Ext ckt may be active; if so, must be limited to open-ckt voltage in range –4 to +20 V, short-ckt current = 10 mA max (+ voltage) or 1 mA max (– voltage).]
		Input	(Same as 5A; refer to $\overline{\text{START}}$/S and INHIBIT, above.)	

*Note: tabulated data apply to instruments as manufactured. Both $\overline{\text{START}}$/S and INHIBIT circuits can be modified by moving wire jumpers. Refer to paragraph 2.8.1.

Pertinent interface requirements are summarized in Table 2-8. For maximum speed, provide active input-signal sources with low internal impedance. For convenience and simplicity, use switch closures.

SENS is an analog input for programming the sensitivity. Provide this signal from a low-impedance source, 15 Ω max at 7 mV for max sensitivity, up to 5 kΩ at 5 V for min.

2.8.3 Single-Circuit Connectors.

BIAS VOLTAGE is an analog signal applied through a rear BNC connector to the capacitor being measured. Provide bias in the range 0-200 V only during fixed-range measurement. (If the RANGE switch is set to AUTO, the bias circuit is internally grounded, presenting 10 kΩ to the BIAS VOLTAGE source.) If the RANGE switch is set to REMOTE, keep $\overline{\text{ARNG}}$ at "1" and program BIAS VOLTAGE to 0 V before every change of the $\overline{\text{RNG}}$-series inputs.

CAUTION

Any range change made with bias voltage applied may damage certain reed switches, resulting in bridge failure.

EXTERNAL METER is a rear-panel (BNC) monitoring point for bias. It is isolated by 100 kΩ from C_xLO (part D of the test cable). Use a meter or recorder of sufficiently high impedance to make negligible the voltage drop across that internal resistor, or compensate for it.

EXT START is the front-panel phone jack, one of several ports for start commands. Plug the appropriate cable of the 1682-P1 Test Fixture in here, when the -P1 is used. Then start each measurement manually by depressing the bed of the test fixture. If high-speed measurements are to be started by this circuit, be sure the start signal (switch closure to ground or logical "0") lasts at least 20 μs. Also hold the opposite condition (open circuit or logical "1") for at least 75 ms. For still higher speeds use the $\overline{\text{SING1}}$ circuit at the AUXILIARY connector.

2.9 TEST FIXTURES.

2.9.1 Standard Test Fixtures.

Several test fixtures are available, to hold a wide variety of capacitors for measurement (Table 1-3). If one of these fixtures is to be used, connect it to the test cable with care that each connector (A, B, C, and D) of the cable mates with the corresponding connector of the fixture.

NOTE

Specified bridge performance depends on proper connections via test fixtures. Do not use clip leads to attach the unknown capacitor or extensions to lengthen the test cable (as might be satisfactory with lower-frequency, less accurate bridges).

2.9.2 Special Test Fixtures.

The capacitor being measured may be held in any test fixture electrically equivalent to a standard fixture. A special fixture may be needed to hold capacitors with a particular terminal arrangement or to meet the particular requirements of automatic handling machinery. Figure 2-8 is the schematic diagram of a typical special-purpose test fixture. Refer also to para. 3.12.

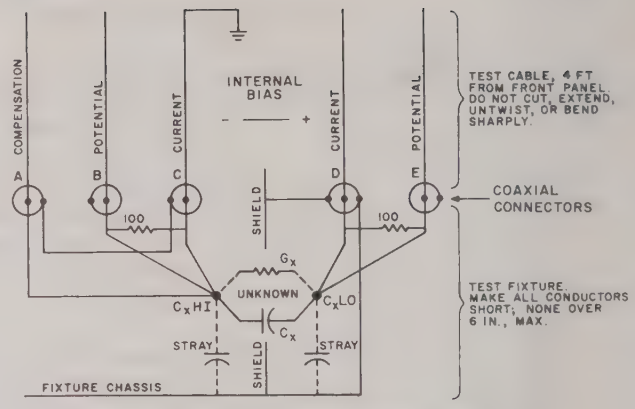


Figure 2-8. Special test fixture schematic diagram. The 100-Ω resistors are recommended only if the current and potential junctions (B-C and D-E) are opened every time the unknown is changed.

Please consult General Radio Co. for advice about the procurement or design of such fixtures.

CAUTION

The test cable must not be altered, untwisted, shortened, or extended. A kink or sharp bend in the cable will affect the most precise measurements. Use hardware supplied with each fixture to clamp the cable about 3 or 4 in. behind the fixture.

2.10 SYSTEM EXAMPLE. Figure 2-9.

An example of a simple automatic capacitor-sorting system makes use of 2 limit comparators and needs no computer. Refer to the block diagram for general layout and cable numbers.

Wire the bin sorter as shown, so that the GO relay of comparator A controls the 1st bin. Set the DATA READY COMMAND CONTROL (A, rear panel) to PRINT OUT-OF-TOLERANCE ONLY, so that comparator B processes the measurement data only if the A limits are exceeded. Wire the 2nd and 3rd bins to comparator B, so that they receive capacitors of acceptable conductance. Arrange the 4th bin to receive "high G" parts. (Its solenoid, if any, can be connected to the normally open terminal of the B-comparator HIGH-G relay.)

Connect the EXT START circuit to a switch that closes to ground every time a capacitor is in position for measurement and opens before the next one.

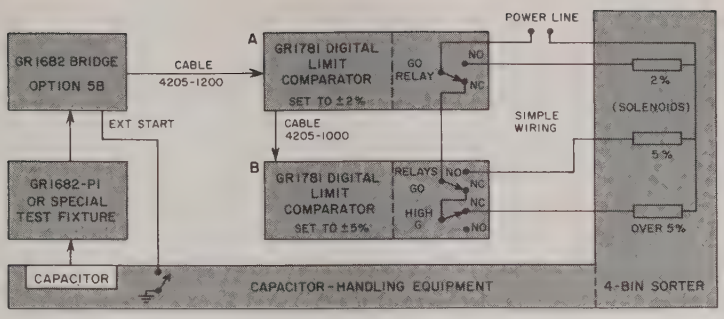


Figure 2-9. A simple automatic capacitor-sorting system.

2.11 CONVERSION TO OPTIONS 5 AND 2.

2.11.1 General.

The bridge can be made more versatile by the installation of a DATA OUTPUT connector, associated N board, and internal cable system, making the instrument a "1682 Option 5." In addition, an AUXILIARY connector, associated Q board, and internal cable system can be added to make a "1682 Option 2."

Option-5 instruments can be converted between the 2 variations, 5A Low Level and 5B High Level, by exchanging the N-board assemblies.

2.11.2 Option 5 — Data Output.

a. Obtain the N-board assembly — 1682-4706 for high-level logic, 1682-4707 for low-level logic — and the interior cable assembly 1682-0205 from General Radio Company.

b. Remove the cabinet and bottom shield cover from the instrument.

c. Install the connector A-J100 (part of the cable assembly) in the space provided, referring to Figure 5-3. Use #4-40, 1/2-in. screws, not provided.

d. Dress the cable along the right side of the chassis to the M board, then between the E- and R-board pins across the M board, parallel to the front panel. Fasten with the cable clamp provided in the instrument.

e. Connect the cable to the M board as outlined in Table 2-9. Each wire is provided with a socket clip to fit an M-board pin. Some of these clips are clamped together to form a connector, where spacing is close enough to do so.

f. Remove the rear-panel plate at the DATA OUTPUT position and install the N-board assembly instead. To do so, insert the board in a high position, from the rear. Engage the board-edge contacts with A-J100 and slide the board straight down until seated. Reinstall the 2 rear-panel screws.

2.11.3 Option 2 — Auxiliary.

a. Obtain the Q-board assembly 1682-4715 and the interior cable assembly 1682-0215 from General Radio Company.

b. Install the connector A-J103 (part of that cable assembly) in the space provided, as described above.

c. Dress the cable along the right side of the instrument. Bring one branch between the D- and E-board pins, the other branch in front of the Z-board pins, parallel with the front panel.

d. Connect the cable to the M board as outlined in Table 2-10.

e. Remove the rear-panel plate at the AUXILIARY position and install the Q-board assembly instead, connecting it with A-J103 as described before.

Table 2-9

CABLE CONNECTIONS FOR OPTION 5 / DATA OUTPUT

Color code	Pin*	Connector	Signal
wh/ye/rd	E-115C	——	ZRNG1
wh/ye/gn	E-114C		ZRNG3
wh/ye/bk	E-113C		ZRNG2
wh/vt/bu	R-109E	A-J101,1	RQ12
wh/gy/rd	108	2	11
wh/vt/rd	107	3	10
wh/vt/gn	106	4	9
wh/gy/gn	105	5	8
wh/vt/bk	104	6	7
wh/rd/gn	103	7	6
wh/gy/bu	102	8	5
wh/rd/bk	101	9	4
wh/gn/bu	R-100E	A-J101,10	RQ3
wh/gy/bk	R-99E	——	RQ2
wh/rd/bu	98		RQ1
wh/or	R-97E		RQ0
wh/or/rd	P-57C	——	+15 V
wh/or/gy	56		–15 V
wh/vt/gy	55		GND2
wh/or/bu	P-54C		+ 5 V
wh/gn	I-50E	A-J102,1	IQ16
wh/ye	49	2	15
wh/br/bk	48	3	14
wh/gn/bk	47	4	13
wh/bu/bk	46	5	12
ye	45	6	11
wh/bk	44	7	10
wh/bu	43	8	9
vt	42	9	8
or	I-41E	A-J102,10	IQ7
wh	I-40E	——	IQ6
gn	39		5
br	I-38E		4
bk	I-37E	——	IQ3
gy	36		2
rd	35		1
bu	I-34E		0
wh/or/gn	P-22C	——	NSING2
wh/or/vt	21		PBUSY
wh/or/bk	20		NINH
wh/ye/bu	P-19C		PABORT

*Prefix M- understood.

Table 2-10

CABLE CONNECTIONS FOR OPTION 2 / AUXILIARY

Color code	Pin*	Connector	Signal
wh/gn	D-114C	——	DIR
wh/bu	D-112C		DRR
br	P-57E	——	+15 V
gn	56		–15 V
bu	55		GND2
rd	P-54E		+5 V
or	P-40C	——	PDBAL
ye	P-30C		PVMR
wh/bu/bk	P-22E	——	PRIG
wh/bk	21		PCLK12
wh/gn/bu	20		NINH
wh/gn/bk	P-19E		QSING1
bk	P-5C	——	PBUSY
wh/rd	P-5E		PABORT
gy	Z-101C	A-J110,6	QSENS
wh/or	100	7	ZROSC
wh/vt	99	8	QOSCL
wh/gy	98	9	ERAN
wh	Z-97C	10	DUNBAL
wh/gy/rd	Z-44C	A-J111,4	ZRNG3
wh/gy/gn	43	5	ZRNG2
wh/vt/bu	42	6	ZRNG1
—	—	—	
wh/vt/bk	40	8	ZRNGO
wh/gy/bu	39	9	ZQRNG
wh/vt/gn	Z-38C	10	QARNG
wh/rd/bk	Z-24E	——	ZRMOD
wh/gy/bk	23		ZSING
wh/rd/gn	22		ZVAR
wh/rd/bu	21		ZTRACK
wh/ye	20		QSETO

*Prefix M- understood.

Operation–Section 3

3.1 PRELIMINARY CHECKS 3-1
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CAUTION

Do not connect a power cord until the line-voltage switch has been set properly.

3.1 PRELIMINARY CHECKS.

Refer to paragraph 1.3 for figures illustrating the controls, indicators, and connectors and for tabulation of their functional descriptions. The recommended initial operating procedure follows:

a. Check that the line-voltage switch on the rear panel is positioned according to the available power-line voltage (either 100-125 V or 200-250 V). To slide this switch up or down, use the tip of a small screwdriver. The power frequency must be in the range 50-60 Hz.

b. Set the bias switch OFF (front panel).

c. Connect the power plug (rear panel) to a suitable power line, using the power cord supplied.

d. Flip the POWER switch up (front panel) and verify that the numerical readouts glow. There is no pilot light.

e. Flip the POWER switch OFF.

3.2 CONNECTIONS AT TEST FIXTURE.

Choose the test fixture according to the type of capacitor to be measured. Figures 3-1 through 3-3 show standard fixtures, for capacitors with standard connectors and those with axial leads. Refer also to paragraph 2.9, where special fixtures are discussed.

Connect the test cable of the 1682 bridge to the test fixture, making sure that each connector is mated with its counterpart, as labeled: A, B, C, D, and E. The 1682-P1 Test Fixture has another cable, which is terminated with a phone plug. Connect this to the EXT START jack on the front panel. Clamp the test cable behind the fixture.

NOTE

Specified bridge performance depends on proper, clean connections via test fixtures. Do *not* use clip leads to attach the unknown capacitor.

3.3 MANUAL SINGLE-MEASUREMENT MODE.

To make measurements in the basic, manual mode of bridge operation, follow this procedure:

a. Set the bridge controls as follows:
   Mode – SINGLE MEASUREMENT.
   RATE – STOP (ccw).
   RANGE – AUTO.
   BIAS – OFF (2nd control at any setting).
   OSC LEVEL – NORMAL.
   SENSITIVITY – MAX (cw); switch to INTERNAL.
   POWER – on (up).

b. Connect a capacitor to the test fixture.

c. Push the START button. Alternatively, if the test fixture is Type 1682-P1 (and is connected to the EXT START jack) press down on the fixture, on or near the bar labeled "PRESS". Usually, the measurement is completed in a very short time.

d. The bridge displays the measured values in the numerical readout until another measurement is started, as in step c. Meanwhile, the measured capacitor can be replaced by an unknown. The UNBALANCE indicator cautions against reading the numerical display as a measurement of the unknown, until the bridge is again balanced.

3.4 PERIODIC RESTART (VMR MODE).

Turn the mode switch to VARIABLE MEASUREMENT RATE if automatic, periodic restarting is desired.

With the associated RATE control, adjust the rate at which the bridge restarts itself. (Each start will be delayed, however, until the previous start cycle has been completed — taking 20 ms — and the corresponding measurement either completed or aborted — up to 2 seconds.) Set the RATE to SLOW to provide a reasonable time to see the results of each measurement.

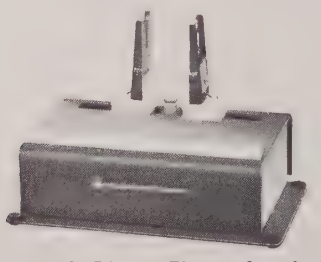

Figure 3-1. 1682-P1 Test Fixture, for wire-lead 2 (or 3) — terminal capacitors. Depress the PRESS bar to start a measurement.

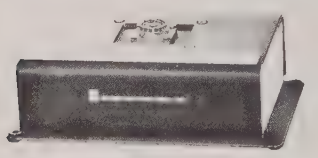

Figure 3-2. 1682-P2 Test Fixture, for 2-terminal coaxial capacitors and standards with the GR900® connector.

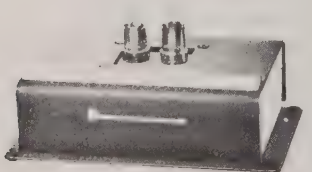

Figure 3-3. 1682-P3 Test Fixture, for 3-terminal shielded capacitors with a pair of GR874®connectors spaced 1 1/8 in apart.

Turn the RATE control to STOP, if it is desired to hold the numerical display of the previous measurement for discussion or to make a written record. Turn the RATE control cw from STOP to make further measurements in this mode.

During a measurement, only those digits in the display that have to change to a new value are altered. A given capacitor can be measured many times with only minor flickering of the numerical readout. The measurements may vary at random ±1 count.

3.5 TRACKING MODE.

Turn the mode switch to TRACKING, if desired, to display continuously-updated measurements. The only display digits to change are those affected by changes in the "unknown" capacitor. There is no periodic cycling of the display.

NOTE

Do ***not*** use bias in this mode with any plug in the EXT START jack. If 1682-P1 Test Fixture is used, leave its external-start plug disconnected to enable biased tracking measurement.

The speed at which the bridge follows rapid change far exceeds the ability of the eye to see — 6000 counts per second. (It counts even faster following a step change.)

There is no way to stop or hold the numerical display (as in the VMR mode). If the mode switch is set to TRACKING, the bridge is in fact balanced or racing toward balance, until the POWER goes OFF.

Refer to paragraph 5.2.6 for the TEST-5 mode, which is similar to TRACKING except for the manually controlled counting speed.

3.6 RANGE SELECTION, AUTOMATIC OR FIXED.

3.6.1 Automatic.

Leave the RANGE switch at AUTO for automatic selection of a range suitable for the capacitor being measured. The bridge indicates its selection by the decimal-point positions and units indicated in the numerical readout.

Most capacitors will be measured at maximum resolution (within the capability of the bridge). But capacitance values beginning with 1 will be measured on either the range of maximum resolution or the next higher range. (The latter obtains if a down-range step would be required to reach the ideal range from the previous measurement). For example, 125 pF will be measured as 125.00 pF (max resolution) if the previous measurement was on the 200-pF range or the lower one. The measurement will be 0125.0 pF if the previous measurement was on a higher range.

NOTE

In AUTO RANGE, no bias can be applied to the unknown capacitor.

Table 3-1
TOP LIMITS ON EACH RANGE

RANGE Name	Capacitance	Conductance
20 pF	19.999 pF	19.99 $\mu\mho$
200 pF	199.99	199.9
2000 pF	1999.9	1999.
20 nF	19.99X nF	19.9X m$\mho$

3.6.2 Fixed Ranges.

Turn the RANGE switch to any one of the 4 ranges, in decade steps from "20 pF" to "20 nF." Refer to Table 3-1 for the top limits on each range. The bridge can balance, provided that neither C_x nor G_x is greater than the corresponding limit of the range selected, and neither is negative. The RANGE indicator lights up if one of these conditions is violated by a significant amount.

For maximum resolution, always select the lowest range which will permit a balance. However, if a batch of similar capacitors is being measured it may be best to use only the range suited to the largest one. The data are then easier to interpret.

Table 3-1 contains "X" in place of the final "9" in each limit of the top range. The true limits exist with "9's" in these places. The "X's" serve as a reminder that these places are not significant (because of accuracy limitations) and are therefore blanked out of the numerical readout.

CAUTION

If bias is applied to the test fixture, whether from an internal or external source, reduce its voltage to zero before (and during) any change of RANGE.

3.7 OPERATIONAL CHECKS AND ADJUSTMENTS.

3.7.1 Introduction.

This paragraph discusses compensation for test-fixture capacitance and the meanings of the front-panel indicators UNBALANCE and RANGE. Access inside the cabinet is not required. Refer to Section 5 for a complete check of minimum performance standards, a more extensive description of adjustments, and the use of TEST modes.

3.7.2 Test-Fixture Capacitance.

Each time a different test fixture is connected to the test cable, and after every change of spacing between the scissor-like terminals of the 1682-P1 (and at other times if desired) make sure that the bridge is properly compensated for shunt capacitance across C_x. Proceed this way:

a. Set the bridge controls as follows:
Mode – TRACKING.
RATE – SLOW.
RANGE – 200 pF.
BIAS – OFF (2nd control at any setting).
OSC LEVEL – NORMAL.
SENSITIVITY – MAX (cw); switch to INTERNAL.
A-S10 (rear panel) – down.
POWER – on (up).

b. Press and hold the SET ZERO button. Verify that numerical displays are zero. Release the button.

c. Adjust A-C24 just to zero-capacitance readout, using a screwdriver at rear panel, as follows: Turn the control as far ccw beyond the position of 00001-pF readout as would be required (turning cw) to reach 00002 pF.

NOTE

Refer to the paragraphs following step f for helpful suggestions.

d. Change to the 2000-pF range. Adjust A-C23 for zero-capacitance readout. (On instruments with ID number 0100 this is an internal adjustment; on later instruments it is a rear-panel screwdriver adjustment.)

e. Change to the 20-pF range. Slide A-S10 (rear panel) **up** only if test fixture is Type 1682-P2. Adjust A-C20 as in step c.

f. Put rear-panel switch A-S10 in proper position for subsequent measurements: **down** for all conditions except **up** for measurements on the 20-pF range with the 1682-P2 fixture.

Axial-Lead Test Fixture. If the fixture is Type 1682-P1, its scissor-like terminals must have scraps of wire (1 in. long) to grip during zero adjustment. If the terminals are close together, a zero adjustment may be possible only if a shield is mounted between them. Make this about 1 in. high (but leave room for the unknown capacitor) and 2 in. wide. Connect the shield with a banana plug to the central jack. Alternatively, slide the terminals apart.

Coaxial Test Fixture. If the fixture is Type 1682-P2, zero adjustment is impossible on the 200-pF range. For step c, adjust instead to some convenient "offset" C_o. Suggested values of offset are 1.33 or 1.40 pF. Subtract this offset from each measurement made on this or higher ranges. The intended use of this fixture is for calibration checks, in which differential measurements are satisfactory.

Multiple Display. In TRACKING mode, occasionally the least-significant digit displays 2 or 3 numerals simultaneously. For example, interpret a superposition of 0, 1, and 2 as a reading of 1. The easiest digit to set in the presence of this effect is 3 because it is farthest forward in the numerical readout tube.

Special Adjustment. There is an internal adjustment, A-C25, intended to modify range of A-C24 adjustment. Refer to paragraph 5.4. (There is no similar padding for A-C20.)

3.7.3 Unbalance Indication.

Interpret the UNBALANCE light (in the center of the numerical readout display) as an announcement that the numerical indication may be grossly in error. The bridge may still be counting toward balance (in which case the numerical display is changing), a counter may have reached its limit (in which case the RANGE warning is usually lit), the measurement may have been aborted, or you may have forgotten to press START. The measurement is invalid.

When the UNBALANCE light is off, the measurement is valid. The bridge is then known to be within a small margin of balance. (Normally the bridge continues to count toward a balance, within this margin, before completing a measurment.) The margin is equivalent to 15 or 20 counts of the least-significant C digit if SENSITIVITY is MAX, and can be broadened to about 68 counts by setting that control toward MIN. (refer to paragraph 3.10.)

3.7.4 Range-Light Indication.

Interpret the RANGE light as an announcement that the bridge cannot make a valid measurement because of inadequate range. Do ***not*** expect this light to indicate when a range change may be desirable for better resolution.

Table 3-1 indicates the top limits for each range. The bottom limits are zero. For example, if the RANGE switch is set to AUTO, the RANGE light (on) indicates that $C_x >$ 19.999 nF, $G_x >$ 19.99 m℧, or $C_x < 0$ (due to inductance), and additionally, that the bridge is not right on the verge of balancing. This indication appears only if the bridge is unbalanced by at least 70 C counts (more precisely: 0.35% of full C range or 2.2% of full G range).

3.8 BIASING THE CAPACITOR.

3.8.1 General.

To measure a capacitor with a bias voltage across it, use either of 2 internal dc sources — 0-10 V and 0-100 V — or connect an external source up to 200 V. Monitor the bias with an external meter. Do not select AUTO RANGE.

CAUTION

Do not change RANGE with bias applied.

3.8.2 Bias Measurement.

Connect a high-impedance dc meter (or recorder) to the BNC jack EXTERNAL METER on the rear panel. Select a meter such that the IR drop across the internal bridge-isolating resistor, 100 kΩ, is negligible compared to that across the meter resistance, for the accuracy desired. (For example, a 100-MΩ meter will read only 0.1% low.) The GR Type 1806-A or 1807 voltmeter is recommended.

WARNING

Bias voltage appears at the test fixture. Take adequate precautions for personnel safety.

The bridge has this safety feature : when the 1682-P1 Test Fixture (or any phone plug) is connected to the EXT START jack, bias can appear at the test terminals only during measurement; bias is automatically shorted out when the bridge reaches balance or abortion. To apply bias in the TRACKING mode, be sure the EXT START jack is empty.

3.8.3 Internal Bias.

Apply bias voltage to the test fixture, and the capacitor under test, by turning the BIAS switch to 10 V. Set the bias anywhere in the range 0-10 V using the BIAS control (labeled 0 at ccw stop and 1 at cw stop). Watch the external meter.

NOTE

The polarity of internal bias is fixed, and indicated on the test fixture.

The C_xHI terminal of the capacitor (A, B, and C of the test cable) is always at ground potential. The C_xLO terminal (D and E) may be biased positive.

For bias in the range 0-100 V, turn the BIAS switch to 100 V and use the BIAS control as described above.

3.8.4 External Bias.

For bias voltage in the range 200-0-200 V, use an external power supply. Connect it to the rear BNC jack labeled BIAS VOLTAGE. Monitor the voltage as described in paragraph 3.8.2. A programmable power supply is ideal for use in a computer-controlled or otherwise automated measurement system. The C_xLO terminal may be + or − with respect to 0 dc voltage at the C_xHI terminal.

3.9 OSCILLATOR LEVEL.

Set the OSC LEVEL switch to LOW if desired to measure capacitors of less than 200 pF with low test voltage. The effective capacitance of nonlinear devices, such as varactor diodes, depends on the test voltage. However, measurement accuracy and precision diminish with the test voltage. So, use the NORMAL LEVEL as a general practice.

Table 3-2 presents test voltage, in rms volts, as a function of LEVEL and RANGE. The table also shows by "X's" that the final digit of each numerical readout is blank when the OSC LEVEL switch is set to LOW except the conductance readout on the 2000-pF range. Thus, most of the inaccurate digits are blanked out. Automatic permanent records of measurements are not abbreviated, however; data output signals are available for every digit.

Table 3-2
TEST VOLTAGE AND READOUT BLANKING VS. OSC LEVEL

OSC LEVEL	RANGE Name	Test Voltage	Readouts	
			Capacitance	Conductance
NORMAL	20 pF	500 mV	12.345 pF	12.34 μ℧
	200 pF	50	123.45	123.4
	2000 pF	5	1234.5	1234
	20 nF	0.5	12.34X nF	12.3X m℧
LOW	20 pF	50 mV	12.34X pF	12.3X μ℧
	200 pF	25	123.4X	123.X
	2000 pF	5	1234X	1234
	20 nF	0.5	12.34X nF	12.3X m℧

3.10 SENSITIVITY.

3.10.1 General.

Keep the SENSITIVITY control at MAX (fully cw) except for special purposes. This setting is necessary for specified accuracy, and permits specified measurement speed.

3.10.2 Noisy Measurements.

Turn the SENSITIVITY control toward MIN (ccw), if necessary to make measurements without abortion in the presence of noise. In some situations, it may be impossible to avoid electrical, mechanical, thermal, or other sources of noise that cause either fluctuations in effective value of the "unknown" capacitor or an addition of electrical noise to the error signal SAMPP in the bridge.

To detect abortion (if the bridge does not include Option 5 or 2) use the SINGLE MEASUREMENT mode; refer to paragraph 3.3. If the numerical readout changes or flickers for an appreciable part of 2 seconds, abortion is likely. If the UNBALANCE indicator is lit after that period, the measurement was certainly aborted. (However, the converse is not certain.)

If the bridge includes Option 5 or 2, detect the digital state of the SHIFT or ABORT signals with a voltmeter; they are unambiguous indications. Refer to paragraph 2.8.

Table 3-3
EFFECTS OF SENSITIVITY SETTINGS

Measured Capacitance Δ	Balance Recognition (Measurement is complete if error signal less than . . .)		UNBALANCE Indicator (It stays lit as long as error signal exceeds . . .)	
	MAX SENS	MIN SENS	MAX SENS	MIN SENS
Any Value*	1 count	51 counts	18 counts	68 counts
Full scale (19999)†	.005%	0.25%	0.09%	0.3%
1/2 Scale (10000)	.01%	0.50%	0.18%	0.6%
1/4 Scale (5000)	.02%	1.02%	0.36%	1.4%
1/10 Scale (2000)	.05%	2.55%	0.90%	3.4%

Δ Note: 1682 accuracy specifications apply only at MAX SENS.
* Error signal expressed in steps of least-significant C digit.
† Error signal expressed in equivalent % of measured C_x.

3.10.3 Range of Control.

Table 3-3 summarizes the effects of the SENSITIVITY control on balance recognition and UNBALANCE indication. Because of the former, this control also effects speed. At MIN, there is a saving of at least 8.3 ms per measurement, generally more, compared to MAX. (Refer to paragraph 3.11.)

Accuracy of measurement depends on SENSITIVITY settings; refer to the "balance recognition" columns of Table 3-3. For example, if you measure a 190-pF capacitor on the 200-pF range, with SENSITIVITY set to MAX, the bridge will come to balance with an error signal < .005%. This is the second term in the accuracy specification (± 0.1% of reading ± .005% of full scale). However, if C_x is 100 pF and sensitivity is MIN, balance error < 0.50%. Expect accuracy, then, to be ± 0.6% of measured value.

Interpolate linearly in Table 3-3. For example, when you measure a 150-pF capacitor with SENSITIVITY set at midrange, expect the accuracy to be 0.1 + 0.18, or ±0.3% of measured value.

3.10.4 Automated Measurements.

If measurements are programmed at high speed, choose the desired compromise between accuracy and speed limit.

For example, suppose 100 pF ±10% capacitors are to be sorted into several categories. Three possible SENSITIVITY settings are then:

1. SENS: MAX, speed: 20/s, accuracy: ±0.11%;
2. SENS: medium, speed: 22/s, accuracy: ±0.36%;
3. SENS: MIN, speed: 24/s, accuracy: ±0.61%.

Table 3-4
TIME REQUIRED FOR A TYPICAL MEASUREMENT

Portion of the measurement process	Time-ms
Fast counting toward balance, until unbalance is down to 0.35% of full range. For each 10% of full range, the required time is:	5.0
For each AUTO RANGE change to next range:	13
For each change in spill digit and/or most significant decade of C:	6
Final balance at slow counting rate, if MAX SENSITIVITY:	12
Final balance at slow counting rate, if MIN SENSITIVITY:	3.4
Slow counting, if previous measurement differed by 0.35% or less, for each 0.1% of full range:	3.3

If the batch of capacitors differs by less than ±10%, the possible speeds are higher and the effect of the SENSITIVITY control is more pronounced. Refer to a further discussion of time delays in paragraph 3.11.

3.11 REMOTE CONTROL.

The 1682 Automatic Capacitance Bridge, Option 2, is completely programmable. Some capabilities, i.e., rapidity of measurement starts and range of bias voltage, are even broader when remotely programmed than when manipulated by front-panel controls. Among the manual functions, only TEST modes and RATE are non-programmable, being intended primarily for service.

Plan the desired system and make interconnections with reference to paragraph 2.8, for input and output signal descriptions and their pin locations in the rear-panel connectors. Interface requirements are also given there; notice that most of the functions are controlled by binary logic signals of widely used types, including passive switch closures to ground. The analog signal SENS is described in the same paragraph, and BIAS in paragraph 3.8.

Set to REMOTE the 5 front-panel switches that are so labeled, unless manual control of the particular functions is desired. (START and SET ZERO functions can always be exercised either manually or remotely.)

Notice that several of the output signals, including DATA OUTPUT, are more complete or precise than their counterparts on the front-panel readouts. Data output signals are complete, never partially blanked as indicated in Table 3-2. $\overline{\text{RAN}}$ indicates an off-range condition even when the error signal is very small, unlike the RANGE light. Either SHIFT or ABORT indicates abortion of measurement, whereas the UNBALANCE light can be interpreted to mean abortion only after 2 s (and will not be lit if the bridge aborts with a very small unbalance).

If the highest possible speed is desired, consider the sequence of measurements to be made and refer to Table 3-4 for the pertinent time delays required by the bridge. Plan the program accordingly, to minimize the total time per measurement. Notice that Table 3-4 never applies in total. For example: each measurement within a batch of 120 pF ±5% capacitors takes no more than 5.0 (120/200) +6 + 3.4 = 12.4 ms at MIN SENSITIVITY. (Refer to paragraph 3.10, about SENSITIVITY.)

3.12 ACCURACY.

3.12.1 Normal.

The normal accuracy of the 1682 Automatic Capacitance Bridge is stated in the specifications and presented in greater detail here. Procedures for the verification of accuracy are included in paragraph 5.2.

Conditions for normal accuracy include the following:

1. SENSITIVITY control switch set to MAX, or the equivalent REMOTE analog signal.

Table 3-5
EFFECTS OF STRAY CAPACITANCE TO GROUND

Range	C_x Measured	Total Stray C	Uncertainty Contribution
20-pF	10 pF	200 pF	1%
200-pF	100	2000	1%
2000-pF	1000	2000	1%
20-nF	10 nF	2000	1%

2. OSC LEVEL switch set to NORMAL, or the equivalent REMOTE digital signal.

3. Stray capacitance to ground is negligible.

4. Test cable is not altered in any way.

5. Test fixture is a standard type or electrically equivalent (paragraph 2.9).

6. Capacitor to be measured is properly connected to the test fixture. (No clip leads; no wax or dirt.)

Determine the accuracy of any particular measurements conveniently by reference to Figures 3-4 through 3-11. These show clearly the "quadrature" or "cross term" uncertainty introduced in each measurement of C_x by the presence of G_x and vice versa. Estimate the additional uncertainty caused by exceptions to any conditions for normal accuracy, as follows:

1. SENSITIVITY not MAX: paragraph 3.10.

2. OSC LEVEL set to LOW: On the top 2 ranges, no effect (except on readout). On the 20-pF range: ±.05% F.S. (effectively 1 count as displayed). On the 200-pF range: ±.005% F.S. (virtually no effect on the displayed measurement).

3. Stray C to ground: paragraph 3.12.2.

3.12.2 Effects of Stray C to Ground.

Table 3-5 presents typical uncertainty or measurement-error contributions resulting from appreciable stray C, i.e., capacitance from C_xHI and C_xLO to ground. The 2 parts of this capacitance are assumed to be equal, from each terminal of the measured capacitor to ground. If the uncertainty percentage is small compared to the normal accuracy, the effect is negligible. Otherwise, add the percentages for a total uncertainty.

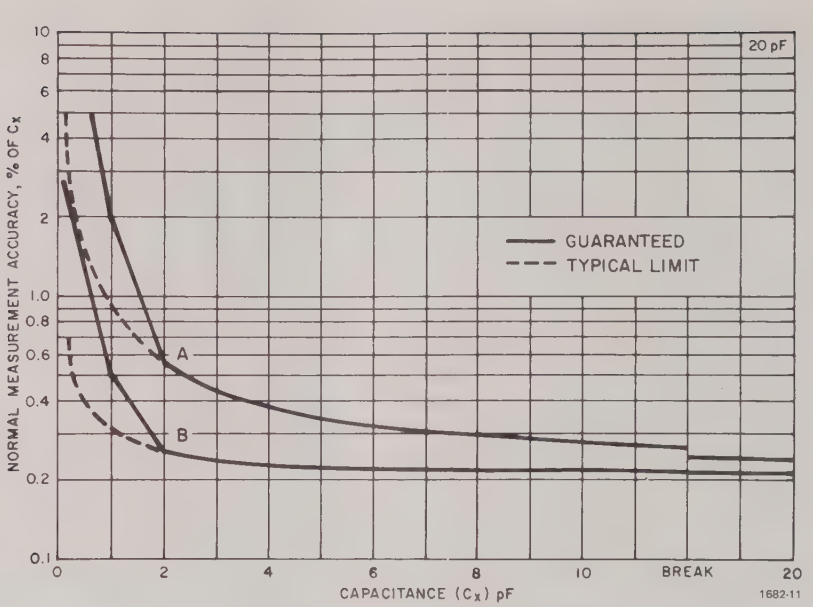

Figure 3-4. 20-pF-range capacitance accuracy. Specification: ±0.2% of C_X ±(1 + 0.6G_X) counts, where unit of G_X is $\mu\mho$; 1 count = .001 pF.
Curve A: Spec for large $G_X \leq 10\ \mu\mho$ (error ≤ 0.2% + 7 counts).
Curve B: Spec for negligible $G_X \leq 0.8\ \mu\mho$ (error ≤ 0.2% + 1 count).

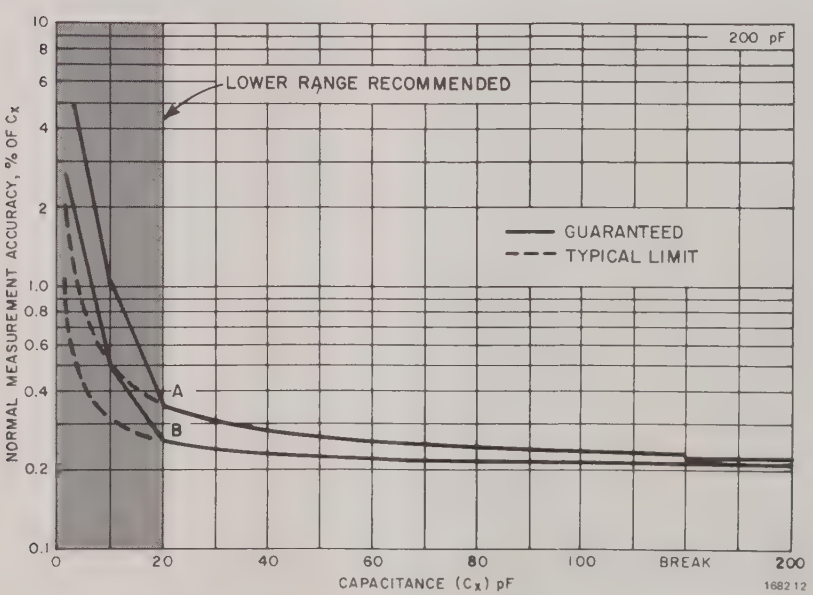

Figure 3-5. 200-pF-range capacitance accuracy. Specification: ±0.2% of C_X ±(1 + .02G_X) counts, where unit of G_X is $\mu\mho$; 1 count = .01 pF.
Curve A: Spec for large $G_X \leq 100\ \mu\mho$ (error ≤ 0.2% + 3 counts).
Curve B: Spec for negligible $G_X \leq 24\ \mu\mho$ (error ≤ 0.2% + 1 count).

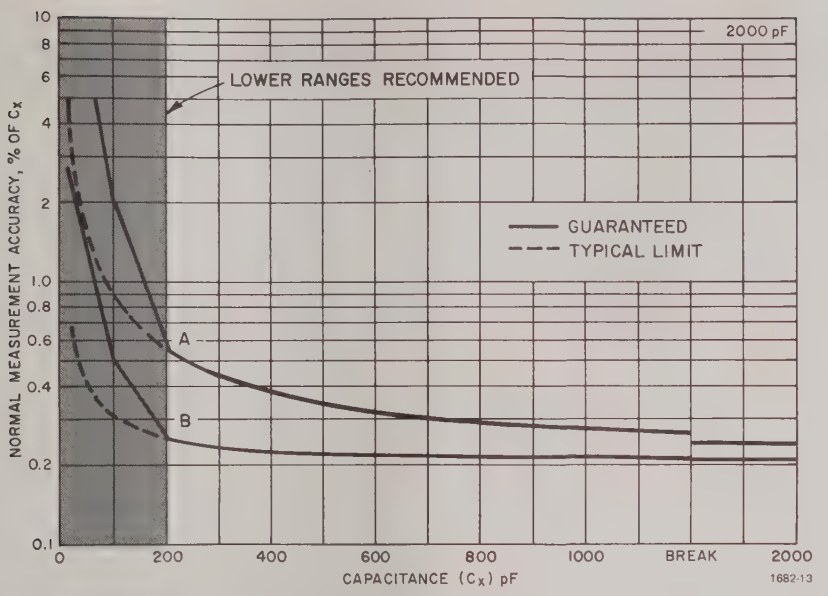

Figure 3-6. 2000-pF range capacitance accuracy. Specification: ±0.2% of C_X ±(1 + .006 G_X) counts, where unit of G_X is μ℧; 1 count = 0.1 pF.
Curve A: Spec for large $G_X \leq 1000$ μ℧ (error ≤ 0.2% + 7 counts).
Curve B: Spec for negligible $G_X \leq 80$ μ℧ (error ≤ 0.2% + 1 count).

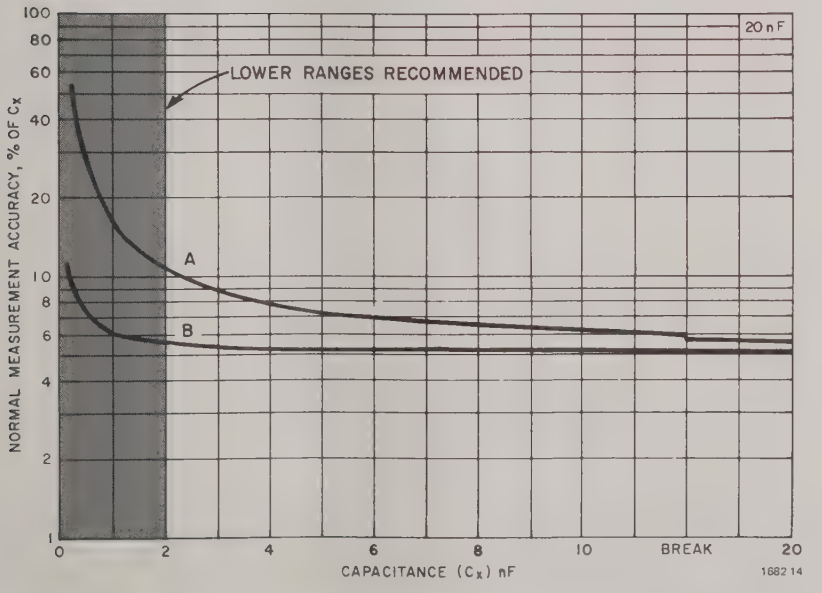

Figure 3-7. 20-nF-range capacitance accuracy. Specification: ±5% ±(1 + G_X) counts, where unit of G_X is m℧; 1 count = .01 nF.
Curve A: Spec for large $G_X \leq 10$ m℧ (error ≤ 5% + 11 counts).
Curve B: Spec for negligible $G_X \leq 0.5$ m℧ (error ≤ 5% + 1 count).

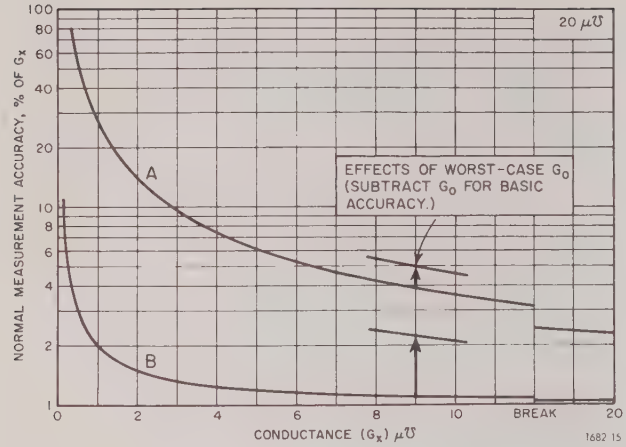

Figure 3-8. 20-pF-range conductance accuracy. Specification: ±1% of G_x ±(1 + 2.5C_x) counts, where unit of C_x is pF; 1 count = .01 μ℧. Definition: $G_0 \equiv$ G offset on this range ($0 < G_0 > 0.1$ μ℧).
Curve A: Spec for large $C_x \leq 10$ pF (error ≤ 1% + 26 counts).
Curve B: Spec for negligible $C_x \leq 0.2$ pF (error ≤ 1% + 1 count).

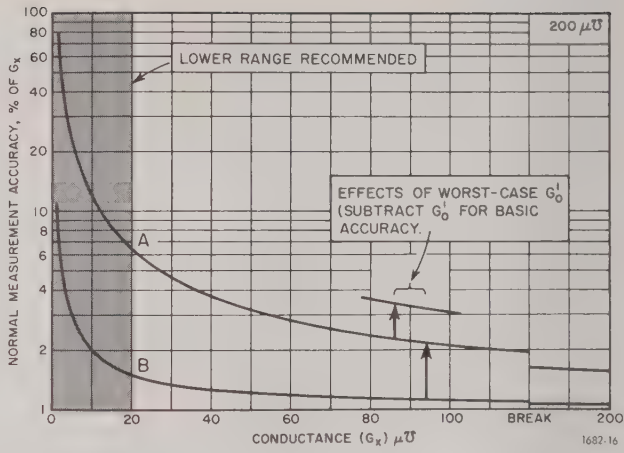

Figure 3-9. 200-pF-range conductance accuracy. Specification: ±1% of G_x ±(1 + 0.1 C_x) counts, where unit of C_x is pF; 1 count = 0.1 μ℧. Definition: $G'_0 \equiv$ G offset on this range ($0 < G'_0 < 1$ μ℧).
Curve A: Spec for large $C_x \leq 100$ pF (error ≤ 1% + 11 counts). Curve B: Spec for negligible $C_x \leq 5$ pF (error ≤ 1% + 1 count).

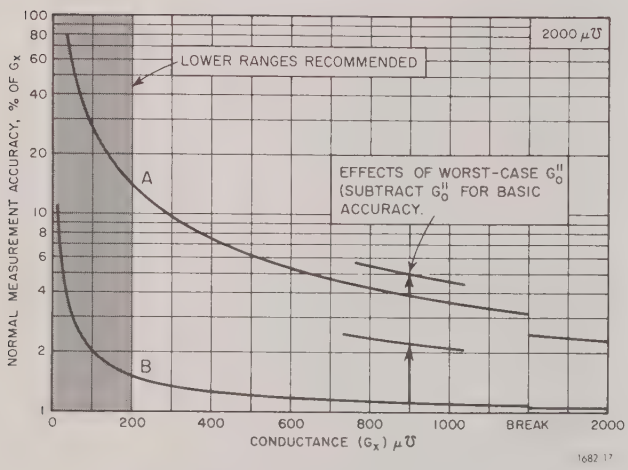

Figure 3-10. 2000-pF-range conductance accuracy. Specification: ±1% of G_x ± (1 + .025 C_x) counts. where unit of C_x is pF; 1 count = 1 μ℧. Definition: $G''_0 \equiv$ G offset on this range ($0 < G''_0 < 10$ μ℧).
Curve A: Spec for large $C_x \leq 1000$ pF (error ≤ 1% + 26 counts).
Curve B: Spec for negligible $C_x \leq 20$ pF (error ≤ 1% + 1 count).

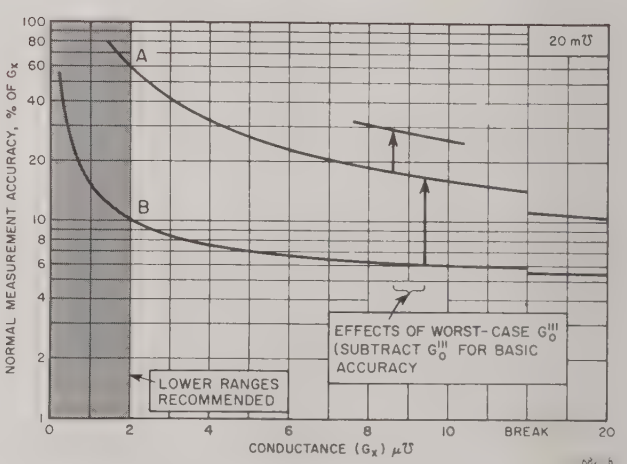

Figure 3-11. 20-nF-range conductance accuracy. Specification: ±5% of G_x ±(1 + C_x) counts, where unit of C_x is nF; 1 count = 0.1 m℧. Definition: $G'''_0 \equiv$ G offset on this range ($0 < G'''_0 < 1$ m℧).
Curve A: Spec for large $C_x \leq 10$ nF (accuracy ≤ 5% + 11 counts).
Curve B: Spec for negligible $C_x \leq 0.5$nF (accuracy ≤ 5% + 1 count).

Theory—Section 4

4.1 GENERAL 4-1
4.2 SIMPLIFIED BLOCK DESCRIPTION 4-2
4.3 BASIC BRIDGE AND BALANCE LOOP 4-2
4.4 RANGE SELECTION 4-4
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4.1 GENERAL.

Basically, under the rather apparent features of convenience and versatility, the 1682 Automatic Capacitance Bridge is reliable because it is a true, ratio-transformer, ac, Kelvin bridge. More precisely, it is a 5-terminal Kelvin double bridge of the type described by Hill and Miller[1] and adapted to 1-MHz measurements by Sette[2].

The inherent stability of its specially-developed low-leakage-impedance ratio transformers is complemented by the quality of its internal capacitance standards. The larger standards are essentially the GR Type 1403 Standard Air Capacitors, which have a stability better than ± .05%/yr, with a temperature coefficient about 30 ppm per degree C.

If the capacitor being measured is, for example, 121.01 pF, it is precisely balanced by parallel-connected 100-, 20-, 1-, and .01-pF standards. The quality of the smaller ones is adequate so that the parallel combination has a stability characteristic like the larger (1403-type) standard capacitors.

This section describes the significant internal circuit functions, signal identification, timing, internal indicators, etc. Except for the simplified block description, the discussion relates to specific subassemblies, for correlation with schematic diagrams and service instructions. The initial letter of each internal signal designates the board where it originates. For example: SAMPP originates on the S board.

In a similar way, each reference designator used in the schematic diagrams and circuit descriptions includes an initial letter, before a hyphen, to identify the board or subassembly (except that A refers to the main frame). The letter before the hyphen may be omitted only if clearly understood, as within a subassembly schematic diagram. Examples: B-R8 designates B board, resistor 8; CR6 on the V schematic is a shortened form of V-CR6, designating V-board, diode 6. The instrument may contain A-R1, B-R1, C-R1, and D-R1.

The theory is detailed in 4 paragraphs (4.3 through 4.6) which deal with signals and functions illustrated by the functional flow diagrams, Figures 6-1 and 6-4. Together these form a comprehensive representation of the bridge.

Except for a few analog signals, such as OREF and ZSENS, internal signals are generally binary, with the characteristics of DTL integrated circuitry. The "0" level is in the range 0 to +0.4 V and the "1" level is +3 to +5 V. These internal signals are similar in nature to the external signals at the AUXILIARY connector; refer to paragraph 2.8.

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[1] Hill, J. J. and Miller, A. P., "An AC Double Bridge with Inductively Coupled Ratio Arms for Precision Platinum-Resistance Thermometry," *Proceedings of the Institute of Electrical Engineers*, February 1963.

[2] Sette, R. F., "Five-Terminal, 1-MHz Automatic Capacitance Bridge," *GR Experimenter*, Nov/Dec 1969.

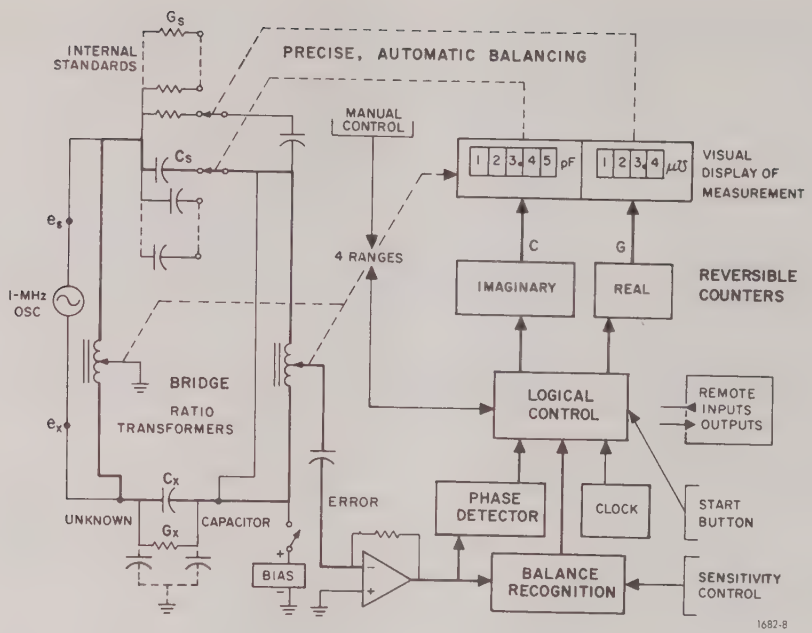

Figure 4-1. Simplified over-all diagram.

Refer to the Signal Index, Table 6-1, for a compendious description of each named signal, external as well as internal.

4.2 SIMPLIFIED BLOCK DESCRIPTION. Figure 4-1.

The basic bridge is the left part of Figure 4-1, with nodes at the terminals of the ratio transformers. Because the drive signal comes from an ungrounded source, the "high" ratio transformer (on the left) determines the ratio between e_s and e_x. They are equal on the 200-pF range. The two ratio transformers always have the same ratio.

Because the error amplifier has very low input impedance, the currents through standard and unknown legs of the bridge are proportional to their admittances. The error amplifier responds to the difference between these currents, with an error signal having a real component proportional to $(G_x - G_s)$ and imaginary component proportional to $(C_x - C_s)$.

A phase detector responds to the polarity of each component, providing direction control for reversible counters. After the control circuit receives a start command, the counters step internal standards C_s and G_s toward balance, i.e., minimum error. The speed of counting is determined by a clock, which switches to a lower frequency as balance is approached.

A balance recognition circuit compares the magnitude of the error signal with a dc reference set by the SENSITIVITY control. When the error is small enough, balance is recognized and the counters are stopped. The visual display, which follows every step of the counters, therefore indicates the values of the standards C_s and G_s, the desired measurement of the formerly unknown capacitor.

On the 20-pF range, the ratio transformers are connected so that e_x is 10 times e_s. Therefore, a 10-times-larger impedance of the unknown capacitor is balanced by the standards. The RANGE switch locates the decimal point one place to the left of its position on the 200-pF range, so the visual display is again the desired measurement. Other ranges use other decade settings of the ratio transformers and appropriate displays of decimal points and units of measurement.

All range-change functions are executed electrically, even when selected by the manual switch. If that is set to AUTO, the bridge counts toward balance (on the range previously determined) until certain limits are reached. Then, logical control circuits stop the counters briefly, while changing to the next range — higher or lower depending on what limit was reached. A suitable range is reached directly.

The foregoing description is based on the SINGLE MEASUREMENT mode of operation, in which the numerical readout is displayed without change, once balance has been reached, until a new measurement is deliberately started. In other modes, logical control circuits start the new measurement automatically after a certain time interval or after any change in the unknown capacitor; the numerical readout tracks each balancing process.

4.3 BASIC BRIDGE AND BALANCE LOOP. Figure 6-1.

4.3.1 The 1-MHz Bridge.

The basic bridge, shown at the left in Figures 4-1 and 6-1, centers at the ratio transformers on the T board.

Physically, the T board is permanently mounted in the heart of the instrument, with the small F board nearby. J, K, and L boards are plugged in farther to the rear. The A parts are mounted on the main frame; the test fixture is external.

OSC is the 1 MHz sinusoidal drive signal, which through an input transformer establishes voltages e_s and e_x at the "high" corners of the bridge, C_sHI and C_xHI (e_s of Figure 4-1 is TOSCS; e_x has no signal name). The ratio of these voltages is determined by the "high" ratio transformer, with its tap at master-ground point AT30.

The "low" ratio transformer always has the same ratio as the "high" one, and also has its tap at (nearly) ground potential. It connects between the "low" corners of the bridge, C_sLO (where the signal designation is LOBU, i.e., low bus) and C_xLO. The signal from this tap is TDET, a 1-MHz sinusoidal current which drives the error amplifier (S board).

The standard arm of the bridge, between C_sHI and C_sLO, has 3 parallel paths. The real path goes through G standards, a ladder network with semiconductor switching, on the J board. At C_sLO, LOBUI has zero dc potential whereas LOBU has the bias, if any is applied to C_xLO.

If only small values of C_x are involved, the imaginary path is controlled by semiconductor switches on the L board. Generally, the 3rd path is also utilized, through reed switches on the K board. Both these paths lead through standard air-dielectric capacitors mounted on a heavy plate in the main frame of the instrument.

4.3.2 Oscillator; O Board.

The crystal-controlled 1-MHz oscillator provides OSC to drive the basic bridge and (at another level) OREF as a phase-detector reference. The O board plugs into the T board.

4.3.3 Error Amplifier; S board.

This differential amplifier responds to the unbalance current TDET and provides the amplified error signal SAMPP. The normal level of SAMPP is 10 mv pk (20 mV pk-pk) per count of C error, summed in quadrature with 16 mv pk per count of G error. The amplifier is tuned to 1 MHz. The S board is plugged horizontally above the T board.

NOTE

The rest of paragraph 4.3 deals with boards which plug into the M board, at the front of the instrument. (H plugs into Z which plugs into M.)

4.3.4 Direction of Count.

On the D board are phase detectors that set flip-flops to determine the directions for the counters to count. DRR depends on the sense of the real component of SAMPP (whether $G_x < G_s$ or $G_x > G_s$) and directs the R counter. DIR depends on the sense of the imaginary component (whether $C_x < C_s$ or $C_x > C_s$) and directs the I counter. The phase detectors operate even when SAMPP is less than 10 mv pk.

DIR and DRR are permitted to change only once per clock cycle, at the "0" transition of $\overline{\text{PCLK12}}$ (part-way between counts). As noted in Figure 6-1, each direction signal turns on a D-board indicator lamp when "0" (forward).

4.3.5 Balance Recognition.

On the D board is a comparator which keeps $\overline{\text{DBAL}}$ "1" while the peak magnitude of SAMPP is greater than the dc level of ZSENS ÷ 10 (which ranges from 0 to 500 mV).

Balance is recognized when |SAMPP| drops to within 10 mV of that level, or below. The comparator then makes $\overline{\text{DBAL}}$ "0". Consequently (as a rule) the Balance Flip-Flop switches to the "balance" state. That — unless the mode is TRACKING or TESTS — will make PRIG "0", which is sufficient to clamp both EICLK and ERCLK to "0", stopping both counters. (Balance recognition also affects the clock; refer to paragraph 4.5.7.)

4.3.6 Clock. **Figure 4-2.**

The clock circuitry on the P board generates 3 outputs. PCLK12 is a train of relatively broad + pulses; $\overline{\text{PCLK12}}$ is the inverse ("1" while the former is "0", and vice versa); PCLK23 is a train of narrow + pulses (0.4 μs wide) with transitions to "1" coinciding with the PCLK12 transitions to "0". Each PCLK23 transition to "0", when the appropriate gates are open, causes the C counter to change by 1 least-significant digit.

4.3.7 Counting Gates.

These gates determine whether each counter continues to receive clock signals. PCLK23, when the C-side gate is open, appears (buffered) as EICLK. When the G-side gate is open, it appears similarly as ERCLK.

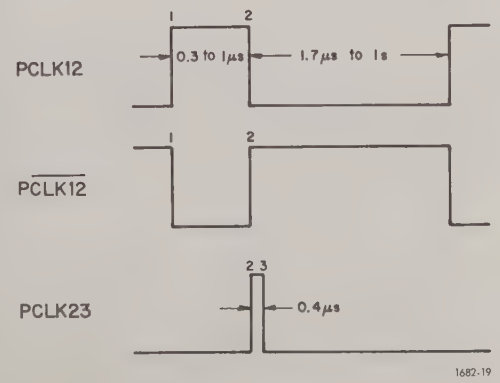

Figure 4-2. Clock signals.

Both gates close and both indicators (E-DS6, E-DS7) are off while PRIG is "0", also for 6 ms after every change of a C standard by K-board reed switches, and for a 6-ms delay during AUTO RANGE change.

One of the gates closes, and the corresponding indicator goes out, when the corresponding counter has reached its top limit and is directed forward — I9$\overline{F}$ or R9$\overline{F}$ is "0". (If this condition causes an AUTO RANGE change, the corresponding gate is closed for another 6-ms preceding the delay mentioned above.)

One of the gates closes, but the corresponding indicator may stay on, when the corresponding counter has reached its zero limit and is reverse-directed — I$\overline{O}$R or R$\overline{O}$R is "0". (Similar action occurs in TESTS mode; refer to paragraph 4.5.)

4.3.8 Counters.

The C counter (I board) provides 2 full sets of 17 signals, 4 each to define the 4 BCD digits and 1 to define the spill digit. The I$\overline{Q}$-series drives the C standards; its complement, the IQ-series, drives the numerical C readout.

The G counter (R board) is similar except for its resolution, having 13 signals in each output series. A divider on the R board generates a special clock pulse for every 10th pulse of ERCLK. The counter steps in the direction specified by DRR at the time of that pulse.

There are no gates on the counter outputs. The C and G standards always have the values specified by the I$\overline{Q}$- and R$\overline{Q}$-series signals, respectively. Similarly, the numerical readouts are always driven by the IQ- and RQ-series signals, although the least-significant digits are kept blank in some positions of the RANGE and OSC LEVEL controls.

4.4 RANGE SELECTION. Figure 6-4.

4.4.1 Manual Switch.

The RANGE switch determines range by making one of the Z$\overline{RNG}$-series signals "0", keeping the other three "1". On the H board, these signals determine which decimal point and unit indicators are illuminated in the numerical readout.

On the Z board (which is intimately associated with the front-panel controls) a set of 4 reed-switch drivers generates the Z$\overline{RR}$-series signals, a ***logical*** duplicate of the Z$\overline{RNG}$-series, but with higher power. The following functions are switched accordingly.

1. Ratios of the ratio transformers (T board).
2. Shunt C_XHI compensation, to ground (T).
3. Series C_XLO compensation, to LOBU (F).
4. C_SHI phase compensation, TOSCS to ground (K).
5. Attenuation, to determine level of OSC (0).
6. Attenuation ahead of the error amplifier (S).

When the RANGE switch selects a fixed range, it also makes ZERNG "0" to prevent auto-range circuits (E board) from affecting any Z$\overline{RNG}$-signals. (The E-board indicators DS1 . . . 4 are then unrelated to the selected range.)

The off-range signal ERAN becomes "1" whenever either counter is directed off range (I9$\overline{F}$, I0$\overline{R}$, R9$\overline{F}$, or R0$\overline{R}$ is "0"). A NAND gate on the H-board responds to ERAN and DVCO so that the RANGE indicator is lit only when the off-range error signal is substantial (SAMPP magnitude equivalent to 70 counts or more; refer to paragraph 4.5.5).

4.4.2 Auto Ranging.

When the RANGE switch is set to AUTO, there is, of course no manual range selection, ZERNG is then "1", enabling the E-board auto-range circuits to determine which of the Z$\overline{RNG}$-series signals is "0". The one selected is, initially, whichever was used in the previous AUTO RANGE measurement. Counting proceeds to balance, unless range-change conditions are met first.

The auto-range logic circuitry will initiate a range increase only if one of the counters is at maximum and directed forward (I9$\overline{F}$ or R9$\overline{F}$ is "0") and the present range is not 20 nF. As long as these conditions exist, E-DS1 is lit. Similarly, it will initiate a range decrease only if both counters are reverse-directed and their two most significant digits are zeros (I00 and R00 both "1") and the present range is not 20 pF. Under these conditions, E-DS2 is lit.

Either of those sets of conditions initiates a range-change sequence, by making the signal at E-TP20 a "0". Refer to Figures 4-3 through 4-5 for a set of timing diagrams, showing the sequence of logical state changes.

There are two delays, T1 and T2, of 6 ms each (during which E-TP3 is "0"). Each delay starts at a "1" transition

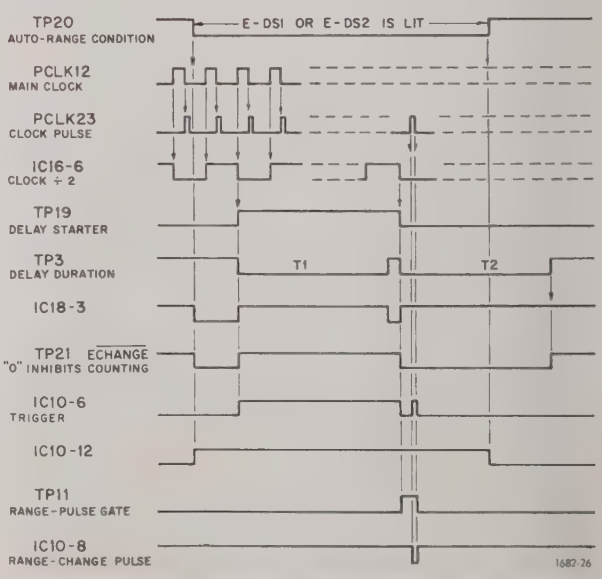

Figure 4-3. Auto-range timing diagram, case 1. The auto-range condition is removed by 1 range change.

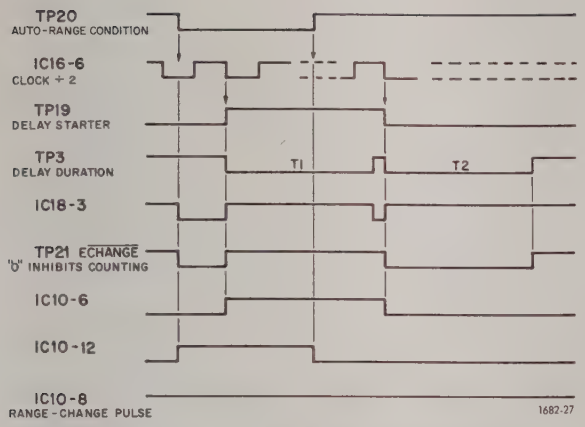

Figure 4-4. Auto-range timing diagram; case 2. The auto-range condition disappears during T1.

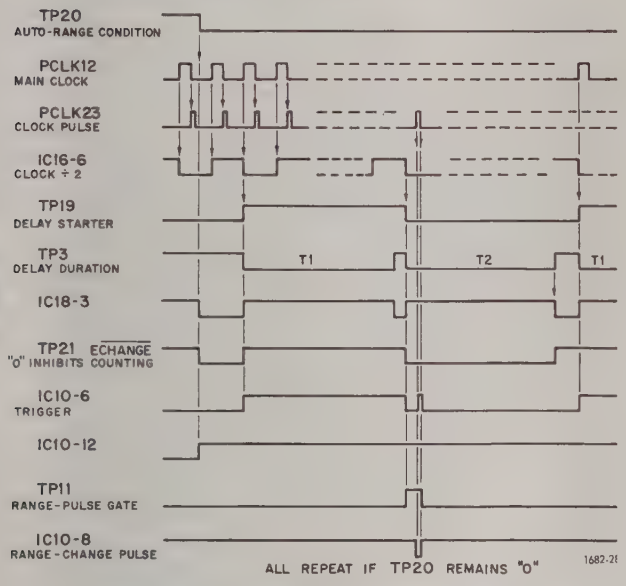

Figure 4-5. Auto-range timing diagram; case 3. The auto-range condition persists after the range change.

of PCLK12 (divided by 2); T1 just after E-TP2 goes to "0"; T2 just after the end of T1. At the beginning of T2, if the conditions are still (or again) right for a range change, the range-pulse gate opens and passes one range-change pulse (coincident with PCLK23) to the range flip-flops, whose states are indicated by lights E-DS3 and E-DS4. (For their logic, refer to Table 5-10.) Each of the 4 possible states of these 2 flip-flops sets one of the ZRNG-series signals to "0".

However, if conditions for range change are not met at the beginning of T2 (typically, E-TP20 has returned to "1" during T1) the range-pulse gate remains closed, as in Figure 4-4. Range is not changed, but the range-change sequence continues anyway, as follows.

During T2, counting is inhibited by ECHANGE being "0", to allow time for reed-switch action and for electrical transients to subside. At the end of T2, the normal measurement process continues, unless the condition for range change persists as in Figure 4-5.

In that case, another T1 delay starts just as soon as the appropriate clock transition occurs, and the whole range-change sequence repeats.

When the down-range conditions exist, lighting E-DS1 as mentioned above, EDWN is "0". On the P board, this acts to keep the balance flip-flop from going to the balance state, even though a balance may be recognized as a result of counting during T1. In that case, counting usually stops with the counters still directed in reverse, and resumes after the range change. (If the balance F-F went to "balance", a start command would be required to resume counting.)

4.5 OTHER FEATURES ON ALL BRIDGES. Figure 6-4.

4.5.1 Mode.

The mode switch determines mode by making one of the following set of 9 signals "0": ZSING, ZVAR, ZTRACK, and the ZT-series. However, ZSING need not be "0"; the single-measurement mode is established if the whole set is "1".

ZVAR enables the start circuit (P board) to be driven from the variable-measurement-rate generator (although other start signals are also valid).

ZTRACK prevents the bridge from completing a measurement. It prevents the balance flip-flop from turning PRIG to "0" (that would close the counting gates). It inhibits the abort circuit, and incidentally prevents the balance flip-flop from inhibiting the VMR generator (as it does during part of each measurement cycle in the VMR mode). In the tracking mode, PRIG is "0" (and therefore the clock is shut off) any time DBAL is "0". However, the moment the unknown capacitor varies as much as 1 count (assuming MAX SENSITIVITY) that situation reverses and the bridge seeks a new balance. Refer to paragraph 4.5.7.

Any one of the ZT-series signals being "0" switches the main clock function from the frequency of the counting-rate oscillator to that of the VMR generator. Any one also (like ZTRACK) inhibits the abort circuit and prevents the balance F-F from making PRIG "0" or inhibiting the VMR generator.

ZT1 through ZT4 are used on the E board to enable one counter, while stopping the other. The same signals, on the D board, determine the direction for the counter that is enabled. They override the phase detectors' control of the direction flip-flops.

4.5.2 Bias.

The BIAS switch selects whether the remote analog signal ABIAS, or one of the internal bias ranges, will determine ZBIAS. That is applied through a T-board filter to C_XLO (the + terminal of the 1682-P1 Test Fixture). The EXTERNAL METER jack is isolated by 100 kΩ from C_XLO.

A reed switch on the Z board shorts ZBIAS to ground, through 50 Ω, in either of 2 situations:

1. If the RANGE switch is set to AUTO.
2. If both a phone plug is in the EXT START jack ($Z\overline{PCON}$ is "0") and the measurement has been completed or aborted (PRIG is "0"). This bias safety feature may not be provided in all instruments; refer to paragraph 3.8.2.

4.5.3 Abortion. **P board.**

When not inhibited by $Z\overline{TRACK}$ or one of the $Z\overline{T}$-series, the abort circuit functions as follows. A latch is reset (making $P\overline{ABORT}$ "1") by the start command (P-TP7 being "1"). Simultaneously, a trigger begins through a 2-s delay, only to be cancelled if the balance FF goes to "balance." Otherwise, at the end of the delay, the trigger reaches the latch making $P\overline{ABORT}$ "0". Because it is used internally on the P board, this signal does not appear in the figure. When $P\overline{ABORT}$ goes to "0", it makes PDBAL "1", flips the balance FF to "balance" (unless auto-range is in process), and makes PBUSY = PRIG = "0", stopping the counters.

4.5.4 Various Front-Panel Controls. **Z board.**

The OSC LEVEL switch, via ZOSC (in conjunction with $Z\overline{RR}$-series signals) acting on attenuators on the 0 board, determines the level of OSC, and therefore the 1-MHz voltage at the test fixture.

In the LOW position of this switch, $Z\overline{BLK}$ is "0", a signal to the H board to blank the least-significant digit in each numerical readout (with one exception).

While the SET ZERO button is depressed, ZSETO is "1" and $Z\overline{SEZR}$ is "0". ZSETO immediately resets both counters to zero (I, R boards) making the standards and numerical readouts also zero. $Z\overline{SEZR}$ pulls $D\overline{BAL}$ and PRIG down to "0" (P, M boards) to prevent any counting as long as the button is held.

The RATE control sets the frequency of the variable-measurement-rate generator, by varying resistance in a circuit returned to −15 Vdc, or stops the generator by closing a switch to ground. The wire connecting the control (Z board) with the rest of the generator (P board) has the signal name ZVARR. However, the sawtooth voltage there is present because of the VMR generator. ZVARR is ***not*** a control signal to the generator (except perhaps, in a digital sense, when clamped to zero).

The START button (or a switch closure to ground, connected via the EXT START jack) triggers the P-board start circuit at the "0" transition of $Z\overline{START}$. Because of an anti-bounce circuit, another start cannot be initiated in this way until at least 75 ms later. However, the bridge measurement is unaffected by how long $Z\overline{START}$ is held at "0", providing that it is held at least 20 μs.

4.5.5 Switching Delay.

On the E board, $I\overline{Q4}$ triggers a pair of holding circuits that close both counting gates for 6 ms after every transition of $I\overline{Q4}$. This ensures a pause during and after every opening or closing of a reed switch in the standard arm of the basic bridge. Counting resumes after transients have subsided.

4.5.6 Counting Rate.

A high rate is necessary to save time while the bridge counts over large changes in its standards. A low rate is necessary for precision of balance as the last few counts are made.

DVCO is "1" for large error signals, SAMPP magnitude exceeding 70 counts or 700 mV pk, and "0" for smaller error. On the P board, DVCO switches the counting-rate oscillator between its 2 frequencies: "1", 400 kHz; "0", 6 kHz.

On the H board, DVCO is used to ensure that the RANGE indicator is not lit for trivial off-range conditions. (For example, a trivial maladjustment of the bridge might make a lossless capacitor appear to have a tiny negative conductance.) Refer to paragraph 4.4.1.

DVCO is also pulled down to "0" for 6 ms by the switching delay function of paragraph 4.5.5. This enhances the prompt recovery of S and D board circuits from switching transients, by reducing some electrical noise related to the main clock.

4.5.7 Balance Recognition. **P Board.**

One consequence of $D\overline{BAL}$ = "0" is inhibiting the counting-rate oscillator. (Paragraph 4.3.5, concentrating on the essentials, only alludes to this function.) This is a refinement, making an excellent instrument better: the moment balance is recognized, the clock stops, making the error signal SAMPP as free from random noise as possible. The clock restarts the moment $D\overline{BAL}$ = "1". This is particularly important in the TRACKING mode, when maximum resolution is needed. With a smoothly varying "unknown", then, the bridge alternately makes a count, waits quietly for the "unknown" to change, makes another count, etc.

4.5.8 Unbalance Indication.

DUNBAL is "1" for an appreciable error signal, SAMPP magnitude > 18 counts (180 mV pk) above the reference level (ZSENS ÷ 10). DUNBAL is "0" for smaller error.

On the H board, DUNBAL = "1" lights the UNBALANCE indicator, to caution the operator that the numerical readout is not an accurate measurement of the unknown capacitor now in the test fixture.

4.6 DATA OUTPUT; PROGRAMMABILITY.

4.6.1 The 1682 Option 5.

Bridges with this option have the N board and the DATA OUTPUT connector. Essentially, these provide the bridge measurement in digital form to peripheral instruments. Refer to paragraph 2.8.1.

The C and G measurements are represented by the $I\overline{Q}$- and $R\overline{Q}$-series signals, respectively, buffered and inverted on the N board. Range information, represented internally by the $Z\overline{RNG}$-series, is converted by N-board logic circuitry into the form described in paragraph 2.8.1.

The $\overline{\text{PRINT}}$ output, "0", is generated whenever PBUSY or $\overline{\text{PABORT}}$ go to "0", indicating the completion or abortion of a measurement. A SHIFT output, "1", is also provided in the abort situation.

The INHIBIT input is buffered and inverted to become $\overline{\text{NINH}}$ internally. $\overline{\text{NINH}}$ = "0" inhibits the start-pulse gen. (P-TP7). The INHIBIT terminal is "pulled" up or down, depending on the position of the wire jumper at N-AT7, to accommodate different peripheral instruments.

The $\overline{\text{START}}$/S input circuit is even more adaptable, by means of wire jumpers at N-AT2 and N-AT3. A set of 10 combinations is given in paragraph 2.8.1. These serve to establish the reference level for a comparator, and to drive it in either sense with $\overline{\text{START}}$/S (with or without a "pull-up" resistor). Provided that $\overline{\text{NINH}}$ is "1", the digital output from the comparator is the internal signal $\overline{\text{NSING2}}$. Its "0" transition is a start signal, acting on the P board in exactly the same way as $\overline{\text{ZSTART}}$.

4.6.2 The 1682 Option 2.

Bridges with this option have the Q board and the AUXILIARY connector. These provide essentials for interface between internal circuitry and a computer or other peripheral instruments in a measurement system.

All the signals on the Q board are buffered except the analog signal SENS, which is filtered to become QSENS, which determines ZSENS only if the SENSITIVITY switch is set to REMOTE.

Several input and output signals are simply buffered and inverted by the Q board; however, $\overline{\text{SETO}}$ and $\overline{\text{STOP}}$ are not inverted. Internal and external names can best be compared by reference to Figure 6-32.

$\overline{\text{RAN}}$, unlike the front-panel RANGE indicator, indicates any off-range condition, even with a very small unbalance.

Remote control of range requires that the RANGE switch be set to REMOTE. Then, if $\overline{\text{ARNG}}$ is "0" (QARNG "1"), $\overline{\text{ZQRNG}}$ is "1" (inhibiting remote selection of range) and ZERNG is "1" (enabling automatic range selection). Then, on the other hand, if $\overline{\text{ARNG}}$ is "1", $\overline{\text{ZQRNG}}$ and ZERNG are both "0", and range is determined by the $\overline{\text{RNG}}$-series inputs. Notice that this series is not inverted on the Q board.

If the OSC LEVEL switch is set to REMOTE, making $\overline{\text{ZROSC}}$ "0", it opens a gate between $\overline{\text{OSCL}}$ and QOSCL. (The gate provides buffering and inversion when open.)

If $\overline{\text{INHIBIT}}$ is "0" it makes $\overline{\text{NINH}}$ also "0", inhibiting the start-pulse generator and the $\overline{\text{START}}$/S function as described in paragraph 4.6.1.

The start signal $\overline{\text{SING1}}$ is not inverted; it passes through a gate to become $\overline{\text{QSING1}}$. $\overline{\text{NINH}}$ controls this gate as well as the one in the $\overline{\text{START}}$/S circuit. $\overline{\text{QSING1}}$, because it is channeled to the P-board start circuit without passing through an anti-bounce circuit, is better suited to computer programming and less well-suited to control by a mechanical switch than $\overline{\text{NSING2}}$ or $\overline{\text{ZSTART}}$.

$\overline{\text{STOP}}$, when "0", forces PRIG to "0" and stops the counters. When "1" it has no control. Although $\overline{\text{STOP}}$ has a bar over the name and PRIG does not, there is no inversion of the $\overline{\text{STOP}}$ signal.

When $\overline{\text{ZRMOD}}$ is "0", because the mode switch is set to REMOTE, it opens gates so that $\overline{\text{SING}}$, $\overline{\text{VAR}}$, and $\overline{\text{TRACK}}$ inputs control $\overline{\text{ZSING}}$, $\overline{\text{ZVAR}}$, and $\overline{\text{ZTRACK}}$, respectively, without inversion.

4.7 POWER SUPPLY. Figure 6-40.

4.7.1 General.

This paragraph is rather detailed because there is more likelihood that field repairs can be made on the V board than most of the other boards.

In addition to the several rectifier-filter circuits the power supply contains 4 series regulators, identified by their output voltages: −15, +15, +10, and +5 V. These are designed to withstand short circuits without damage. They are interrelated, the primary reference being one Zener diode V-CR6, and the primary adjustment being in the −15-V regulator.

There is an unregulated output at +250 V. Primarily for the numerical readout tubes, this is also used for the 100-V bias supply (with a Zener-diode circuit on the Z board).

A protective switch A-CB1 is included to prevent the instrument from operating with the +5-V bus at an abnormally high voltage which would damage the integrated logic circuits.

4.7.2 Rectifiers and Filters.

Primary line power is brought to transformer A-T1 through front-panel switch A-S50, rear-panel switch A-S51 (which adapts the instrument to either 115-V or 230-V) and the protective switch contacts.

Normally the Zener diode in A-CB1 carries no current. But if the +5-V bus rises above 6.2 V, the diode breaks down and very quickly heats the thermosensitive element making it break the primary power circuit. A-CB1 acts rapidly enough to protect the integrated circuits throughout the instrument; resetting is automatic after a brief cooling period.

The +21.5-V and −21.5-V rectifier circuits are together a split-bridge configuration, or they may be thought of as two full-wave rectifier circuits utilizing the same tapped transformer winding.

The 10-V floating and the +250-V rectifiers are simple bridges, with a more elaborate filter on the latter.

WARNING

The 250-V supply is dangerous. Even with the POWER OFF, lethal voltage persists for an appreciable time. Do not trust the bleeder. Short A-T1, 18 to A-T1, 19 with a wire before touching this circuit. (Refer to Figure 5-2.)

4.7.3 The −15-V Regulator.

This is the only independent regulator, having its own reference, voltage adjustment, current limiting, and self-starting circuitry.

The reference diode is CR6. (The prefix V is understood: V-CR6 is a 6.8-V reference.) Its temperature coefficient tends to compensate that of the Q5 emitter-base junction.

The first amplifier Q5 is driven by the difference between the reference level and a fraction — set by adjustment R18 — of the output voltage. Suppose that output level is more positive than desired (as during start-up). Q5 is pushed toward cutoff, and its collector voltage becomes more negative. So does Q6 base.

Second amplifier Q6 takes part of the current from current source Q8, leaving the remainder to drive the Darlington pair Q7 and A-Q51. As the base voltage of Q6 decreases, it passes less current, but Q7 base receives more.

The more current Q7 receives, the more it sends on (amplified) to A-Q51, reducing the series impedance between the source terminal "A−21.5 V" and the −15 V bus. So the sense of the feedback is correct.

C3 and R10 comprise the additional circuitry needed for stability.

CR4, leading to a resistive divider, assures that Q8 is turned on initially, when the voltage at the output bus may be zero. CR5 takes over the function as soon as A-Q51 is conducting normally.

R9 and CR3 add short-circuit protection. When the IR drop in R9 exceeds the sum of the forward drops in CR3 and Q6-base-emitter junction, an additional increment of current passes through Q6. This increment is not significant in normal operation, but flows when the power supply is overloaded or short circuited. As in normal operation, increasing the current through Q6 causes an increase in A-Q51 impedance. Also, because normal output voltage cannot be maintained, Q8 supplies less current (down to the start-up value). As a result, A-Q5 limits the short-circuit current to a safe value, substantially below the maximum available with normal regulation.

4.7.4 The +15-V Regulator.

This regulator provides power at the same voltage as the −15-V regulator except for positive polarity; it has no internal reference or voltage adjustment, but does have current limiting.

The first amplifier Q1 is driven by the average voltage between the +15 and −15-V busses. CR2 is forward biased and has the proper temperature coefficient so that Q1 base is normally just at 0 V. Suppose the output level is more negative than desired (as during startup). Q1 is pushed toward cutoff and its collector voltage becomes more positive. So does Q2 base.

Second amplifier Q2 supplies part of the current to current-source Q4, the rest coming from Q3 base. As the base of Q2 goes positive, it supplies less current, so Q3 must supply more.

The more current Q3 passes, the lower the impedance of its Darlington companion A-Q50 and, therefore, the higher the voltage on the +15-V bus.

The feedback loop is stabilized with the addition of C1 and R2. R1 and CR1 add short-circuit protection, as explained before.

4.7.5 The +5-V Regulator.

This regulator depends on the −15-V regulator for reference and the +15-V regulator for a current source; it has no internal reference or voltage adjustment, but does also have current limiting.

Differential amplifier Q11/Q12 compares a point on a voltage divider (R28/R29) with zero. Suppose the −15-V bus is normal and the +5-V-bus level is low (as during startup). Q11 current is more than normal; Q12 current less. Q12 collector (and therefore Q9 base) voltage decreases.

Second amplifier Q9 takes part of the current from current source Q13, leaving the remainder to drive Darlington pair Q10 and A-Q52. As the base voltage of Q9 decreases, it passes less current, making Q10 base receive more.

The more current Q10 receives, the more it sends on (amplified) to A-Q52, reducing the series impedance between ground and the negative source terminal "A, 10 V floating." The sense of the feedback is correct to maintain the positive terminal at +5 V, as desired.

C6 and R24 comprise the additional circuitry needed for stability of the feedback loop. R25/R26 and CR7 add short-circuit protection as explained before.

4.7.6 The +10-V Regulator.

This regulator depends on both the +15-V and +5-V regulators for reference; it does have a voltage adjustment and simple but effective short-circuit protection.

Differential amplifier Q14/Q17 compares a point on a voltage divider with the level of the +10-V bus. The voltage adjustment R34 is part of that divider. So is CR8, which acts to compensate for temperature effects in the transistors. Suppose the references are normal but the +10-V-bus voltage is low (as during startup). Q17 current is less, and Q14 more than normal.

Second amplifier Q16 base current is a large part of Q14 collector current, so Q16 conducts strongly. Similarly, the amplified current increase is passed via Q16 emitter to Q15 base, reducing series impedance in the main current path and increasing the voltage on the +10-V bus.

Short-circuit protection is provided in R36 simply by its IR drop. The normal current demanded from this regulator is small enough so the dissipation in R36 is insignificant.

4.8 COMPENSATION CIRCUITRY. Figure 6-4.

4.8.1 General.

The compensation circuits serve chiefly to maintain accuracy of the bridge by minimizing certain consequences of stray parameters such as series impedance in the test cable, leakage impedance in the ratio transformers, and various shunt admittances. Figure 6-4 shows the compensation circuitry in relation to the whole bridge.

4.8.2 Shunt Loading (T board). Figure 6-38.

Load admittance is placed from the X (unknown) side of the HI ratio transformer to ground to balance stray load on the S (standard) side.

Ideally, the ratio e_s/e_x would depend only on the transformer ratio. However, especially at ratios far from 1:1, shunt loading effects are appreciable. When all the C standards are connected, the effect of the many ground capacitances in the switching circuitry (shunting the S side) would be to reduce e_s/e_x. However, that effect is minimized by connecting a proportionate load across the X side. T-K118S and T-C5 (for example) are used on the 2000 pF range.

There is also ***conductance*** shunting the S side (L-board buffer-amplifier input impedance). The phase compensation is a proportionate conductance on the X side; see T-R3 and the adjustable T-R9.

On the 20-nF range, the proportion is different because of the different transformer ratio. However, similar compensation is achieved by T-K117S switching T-C8 and those parts in parallel with it, including the phase adjustment T-R10.

4.8.3 Shunt Loading (K board). Figure 6-21.

Load admittance is placed across the S side of the HI ratio transformer to balance unavoidable shunt load on the X side.

This situation, which is exactly the converse of the one described before, requires compensation on the 20-pF and 200-pF ranges. Test-cable and other capacitance between CxHI and ground are balanced by capacitors connected between TOSCS, which is CsHI, and ground.

On the 200-pF range (1:1 ratio) K-K17S connects K-C35. On the 20-pF range, K-K7S connects a more elaborate compensation circuit including K-C19 and a phase adjustment K-R34. Notice that the range of this phase adjustment is controlled by the size of T-R12, connected across the opposite side of the ratio transformer through T-K121S.

4.8.4 Standards Switching (K Board). Figure 6-21.

Ground-capacitance load is added to the S side of the HI ratio transformer whenever one of the large C standards is disconnected.

Consider the 100-pF standard A-C3, controlled by the signal I$\overline{Q}$0. Notice that K-K5S and K-K6S are closed alternately (K-K6S and K-K16S close at the same time). When K-K5S opens, capacitance from K-AT5 to ground is removed from the S side of the HI ratio transformer. As explained above, the S-side load has been compensated by loading the X side. Rather than change that compensation, we chose to load the S side with another capacitance equal to the one removed. K-K6S does this by connecting K-C11 between TOSCS and ground.

Similar circuitry pertains to each of the 5 large C standards. For example, when K-K1S opens, disconnecting A-C1 (and K-K12S closes) it follows that shunt loading between TOSCS and ground would be reduced unless K-K10S closes, connecting K-C16.

Notice that the need for such compensation depends on the ratio of e_s/e_x. In practice, K-board shunt compensation is needed only on the 2000-pF and 20-nF ranges; failure of this circuitry would be detrimental only on these 2 ranges.

4.8.5 Capacitance Offsets (K, T boards).

Capacitors are connected in 2 ways to cancel test-fixture capacitance, so that the bridge can be adjusted to read ***directly*** the Cx beyond (attached to) the fixture.

The most apparent way to balance test-fixture capacitance is to connect a proportionate amount of C across the standard arm of the bridge. The proportion depends on the ratio transformer. For example, on the 200-pF range, A-C25 (adjustable) and, on the 20-pF range, K-C34 (and, when A-S10 is closed, A-C32, both fixed) are connected between TOSCS and LOBU. However, these capacitors are deliberately chosen to overcompensate the normal test-fixture capacitance, balancing additionally the capacitors described below. The 2 top ranges have enough stray capacitance across the standard arm so that no additional capacitors are needed there.

Capacitors are deliberately connected across the test fixture, balancing the "over compensation" mentioned above. On all but the top range, variable capacitors are used, being adjusted with a screwdriver at the rear panel. The capacitors are A-C20, A-C24, A-C23, and A-C30 for the 20-pF . . . 20-nF ranges, respectively (Figure 6-38). The appropriate adjustment to compensate for an increase in test-fixture capacitance is, of course, a decrease in each of these capacitors.

These 4 capacitors are connected diagonally across the bridge, from CxHI to LOBU. For the purpose intended, that connection is equivalent to a parallel connection across Cx. (CxLO and LOBU have nearly the same signal potential.)

4.8.6 Resonant cancellation (F board). Figure 6-12.

Series capacitance is inserted in the "current" path between CsLO and CxLO to resonate with series inductance of the test cable.

A very low impedance is required between the LO corners of the bridge so that the "current" and "potential"

distinction (between test-cable paths D and E) of the 5-terminal bridge is valid. The resonance is not critical (is low-Q). However, requirements vary among the ranges (because of leakage inductances) from the direct connection of the 20-pF range to the reactance of F-C3 on the 20-nF range.

Service and Maintenance—Section 5

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5.6 RECALIBRATION 5-15
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5.1 GR FIELD SERVICE.

The two-year warranty attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone the nearest GR service facility (see back page), giving full information of the trouble and of steps taken to remedy it. Describe the instrument by type number (front panel), serial, and ID numbers (rear panel).

Instrument Return. Before returning an instrument to General Radio for service, please ask our nearest office for a "Returned Material" number. Use of this number in correspondence and on a tag tied to the instrument will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

For return shipment, please use packaging that is adequate to protect the instrument from damage, i.e., equivalent to the original packaging. Advice may be obtained from any GR office.

Fault Isolation to the Board Level. Detailed instructions are included in this manual to isolate a malfunction to a particular etched-circuit board or a group of boards. Because of etched-circuit complexity and the difficulty in troubleshooting down to the detail-part level, it is strongly recommended that repairs be handled by replacement of the circuit board. (For those who desire to troubleshoot to the detail-part level, the manual includes information such as voltages and waveforms on the schematic drawings, parts lists, and circuit description in the theory section.)

In order to expedite the repair or replacement of the defective etched-circuit board, use the following procedure:

Substitution of Plug-In Boards. Contact the nearest General Radio repair facility (listed on the last page). Give the type, serial number, and identification (ID) number of the instrument, the letter designation and part number of the defective board (refer to the parts list), and a purchase order number. The P.O. number is needed for billing, if the unit is out of warranty, and for identification to expedite replacement. The repair facility will arrange for a replacement board to be shipped as quickly as possible. Return the defective board in the packing supplied with the replacement, or equivalent packing, to ensure against further damage in shipment. Please identify the defective board, with the "Returned Material" number, using the tag furnished with the replacement. Make the return shipment to the address indicated on the tag.

5.2 MINIMUM PERFORMANCE STANDARDS.

5.2.1 General.

The equipment, methods, and criteria for verifying the specified performance of the 1682 bridge are given below. Pertinent adjustments are described in para. 5.4 through 5.6. If performance is grossly inadequate, erratic, or cannot be corrected by the adjustments, refer to trouble analysis, para. 5.7.

Set the front and rear-panel controls to the standard positions of Table 5-1, except as specified otherwise, in all procedures of Section 5.

Equipment needed for the measurements and procedures of Section 5 is listed in Table 5-2.

NOTE

Cleanliness is important for the GR900® precision connectors on your test fixtures and standards. Use the cleaning kit as directed.

Table 5-1
STANDARD SETTINGS FOR 1682 EVALUATION

Control	Setting
Mode	SINGLE MEASUREMENT
RATE	STOP (ccw)
RANGE	200-pF
BIAS	OFF (2nd control at any setting)
OSC LEVEL	NORMAL
SENSITIVITY	MAX (cw) or slightly below MAX, to eliminate flickering (See para. 3.10.)
SENSITIVITY switch A-S10 (rear)	INTERNAL
POWER	Down On (up)

Table 5-2
TEST EQUIPMENT

Item	Requirements	Recommended Type △
Oscilloscope	Bandwidth: dc – 50 MHz; Deflection factor: 5mV/cm – 20 V/cm; Display: alternate channels.	Tektronix 547 with 1A1 plug-in unit, two P6008 probes, and one P6028 probe.
Test fixture	Standard 1682 accessory, for a single GR900® connector.	GR 1682-P2
Test fixture	Standard 1682 accessory, for a pair of GR874® connectors.	GR 1682-P3
Precision variable capacitor	Range: 10-110 pF; Terminals: 3; Terminal-C sum: 100 pF, max; Accuracy at 1 kHz: ±0.01 pF; Series L: 0.13 μH, nominal.	GR 1422-CLP (or 1422-CL with precision calibration).
Coaxial capacitance standards with GR900 connectors.	1, 2, 5, 10, 20 pF.†	GR 1405-A to -E.
	80 pF	GR 1406 (special)
	50, 100, 200, 500, 1000 pF.†	GR 1406-A to -E.
	.002, .005, .01 μF.†	GR 1407-B, -C, -D.
Conductance references (axial-lead resistors)	Stable, low-inductance resistors; Type: metal film all of one type; Accuracy: ±0.1% except as noted; Values: 68*, 100*, 200*, 680 Ω; 1, 2, 6.8, 20, 68, 100, 200 kΩ; pair 10 kΩ matched within 0.02%; 1 MΩ ±5%.	IRC type CEC or Dale MFF-½

Table 5-2 (cont)

TEST EQUIPMENT

Item	Requirements	Recommended Type △
Component mount	For precision resistors.†	GR 900-M
Axial-lead capacitors	Type: silvered mica; Accuracy: ±10% or better; Values: 10, 100, 1000, and 10,000 pF.	CDE types CD15 --, CD19 --, and CD30 --.
Axial-lead resistor	Type: composition; Size: ¼ watt; Value: 100 Ω ±5%; 1 required.	–
Elbow connectors	To fit 1682-P3 Test Fixture; 2 required.	GR 874-EL
Tee connectors	To fit 1682-P3 Test Fixture; 2 required.	GR 874-T
Binding-post adaptors	To fit tees; 4 required (called coupling probes).	GR 874-MB
Plugs	To fit binding-post jacks; 10 recommended.	GR 874-DB
Socket clips	To fit pins on M board; 10 recommended.	Berg terminal 47384
Voltmeter	Range: 15 mV to 1500 V; Accuracy: ±0.5%.	GR 1807
Multimeter	Ohmmeter min reading: 0.2 Ω max; Ohmmeter test voltage: 1.5 V max.	GR 1806
Autotransformer	Voltage rating to match available power line. Metered, to read voltage and current.	GR W5MT3A (120-volt) or W20HMT3A (240-volt)
Direction controller	A manual switching circuit for setting DIR and DRR; to be constructed by the customer.	Refer to Figure 5-1.
Cleaning kit	For GR 900® connectors.	GR 900-TOC
Extender boards	Set of 3. Refer to Table 1-3.	–

△Equivalents may be substituted.

†For use with 1682-P2 Test Fixture; for requirements and part numbers: Table 1-3.

* Accuracy: ±1% or better.

5.2.2 Initial Checks.

The following procedure verifies that the bridge is operative.

CAUTION

Be sure the line-voltage switch on the rear panel is properly set for the available power.

a. Connect the 1682-P2 Test Fixture to the test cable, making sure that connectors A, B, C, D, and E are mated with their counterparts.

b. Set the controls to standard settings (para. 5.2.1).

c. Connect the 100-pF C standard to the text fixture.

d. Press the SET ZERO button.

e. Verify that the numerical readouts are 000.00 pF and 000.0 n℧.

f. Turn the RANGE switch and verify that the decimal points move left and right with the switch, except on the 20-nF range which should read 00.00 nF and 00.0 m℧. Return to the 200-pF range.

g. To check the G display, turn the mode switch to TESTS 3 (G forward) and advance the RATE control slowly to a middle position. Verify that the right-hand digit steps through its 10 counts normally. Advance the RATE control cw as is convenient to check the next digit, and then the next, etc., until the limit is reached — 199.9. Return the RATE control to STOP. Press SET ZERO.

h. Check the C display similarly, with the mode switch at TESTS 1 (C forward).

Verify that UNBALANCE and RANGE indicators are lighted, but that they go off when the mode switch is returned to SINGLE MEASUREMENT; if necessary press the START button. Return the RATE control to STOP.

5.2.3 Zero Adjustments and Offsets.

a. Install a 20-pF coaxial capacitance standard in the 1682-P2 Test Fixture. Be sure the controls are at standard settings, particularly that SENSITIVITY is near MAX.

b. Switch to the TRACKING mode. Adjust A-C24 (rear panel; screwdriver) to make the C readout 21.63 pF or whatever is required to make the offset 1.6 ± 0.1 pF. The least-significant digit should be 3, with flickering (if any) equalized between 2 and 4. Subtract the 1-MHz value of the standard from the readout to obtain the offset, C_o. Record this value for use in para. 5.2.4.

c. Verify that the G readout is less than 10 counts, i.e., 000.0 to 000.9 μ℧. This zero-G readout is the conductance offset G'_o for this range. Record the conductance offset in steps c, d, e, and f for use in correcting G measurements to maximum accuracy. (Refer to para. 3.12.)

d. Switch to the 2000-pF range and install a 200-pF coaxial capacitance standard; verify that the conductance readout is 0000 to 0009 μ℧, and the UNBALANCE indicator is off. Record G''_o. Adjust the capacitance offset to exactly equal the setting in step b, using A-C23. That is, make the readout equal to the 1-MHz value of the standard plus C_o.

e. Switch to the 20-nF range and install a .002-μF coaxial capacitance standard. Verify that the numerical readouts are 02.00 nF ± 5% and 00.0 to 00.9 m℧, and the UNBALANCE indicator is off. Record the offsets C'_o and G'''_o.

f. Switch to the 20-pF range and install a 2-pF coaxial capacitance standard. Adjust A-C20 for an offset of C_o, as before, i.e., to make the C readout equal to the 1-MHz value of the 2-pF standard plus C_o. Verify that the G readout is 00.00 to 00.09 μ℧, and the UNBALANCE indicator is off. Record G_o.

NOTE

It is not necessary to obtain the same offset (C_o) for each of the 1st 3 ranges; but Table 5-3 is based on this adjustment, and it makes the bridge most convenient for general use.

g. Switch to the SINGLE MEASUREMENT mode.

5.2.4 Capacitance Calibration Check/Table 5-3.

a. Install the 1-pF coaxial capacitance standard on the test fixture.

b. Press START; verify that the bridge measurement is within the limits given in the table.

c. Press SET ZERO and then repeat step b.

d. Substitute the next standard indicated in the table; repeat steps b and c. Continue in this way until the first range has been checked out.

e. Proceed, as above, to check out all ranges following Table 5-3 as a guide. Verify that the bridge performs within the tabulated limits. (The offsets C_o and C'_o are obtained through paragraph 5.2.3.)

5.2.5 Conductance Calibration Check/Table 5-4.

a. Install a component mount on the test fixture, replacing the coaxial capacitor.

NOTE

The 900-M component mount is supplied originally with 2 binding posts and a central screw. Remove one of the binding posts. Use the remaining post and screw as terminals.

Table 5-3

C – CALIBRATION CHECK LIMITS

Range	Coaxial standard	1-MHz value of standard	Bridge readout
20-pF	1-pF	A pF	A + C_O ± .005 pF
	2	B	B + C_O ± .005
	5	C	C + C_O ± .011
	10	D	D + C_O ± .021
200-pF	10-pF	E pF	E + C_O ± .05 pF
	20	F	F + C_O ± .05
	50	G	G + C_O ± .11
	100	H	H + C_O ± .21
2000-pF	200-pF	I pF	I + C_O ± 0.5 pF
	500	J	J + C_O ± 1.1
	1000	K	K + C_O ± 2.1
20-nF	.002-μF	L nF	L + C_O' ± .11 nF
	.005	M	M + C_O' ± .26
	.010	N	N + C_O' ± .51

Table 5-4

G – CALIBRATION CHECK LIMITS

Range	Conductance reference	1-MHz value of reference	Bridge readout
20-pF	200 kΩ	5 μ℧	5 + G_O ±.06 μ℧
	100	10	10 + G_O ±0.11
	68	14.71	14.71 + G_O ±0.16
200-pF	20 kΩ	50 μ℧	50 + G_O' ±0.6 μ℧
	10	100	100 + G_O' ±1.1
	6.8	147.1	147.1 + G'_O ±1.6
2000-pF	2000 Ω	500 μ℧	500 + G_O'' ±6 μ℧
	1000	1000	1000 + G_O'' ±11
	680	1471	1471 + G_O'' ±16
20-nF	200 Ω	5 m℧	5 + G_O''' ±0.4 m℧
	100	10	10 + G_O''' ±0.6
	68	14.7	14.7 + G_O''' ±0.9

b. Insert a 200-kΩ conductance reference in the mount. Switch to the 20-pF range.

c. Press START; verify that the G measurement is within the limits given in the table. (The offset G_O is obtained through para. 5.2.3.)

d. Press SET ZERO and repeat step c.

e. Substitute the next conductance reference indicated in the table; repeat steps c and d. Continue this way until the first range has been checked out.

f. Continue the checkout, through Table 5-4.

5.2.6 Auto-Range and Modes.

Check the modes of operation, using the setup of the preceding paragraph.

a. Turn the RANGE switch to AUTO.

b. Connect a 10-nF capacitor. Press START.

c. Verify that the bridge comes to balance on the appropriate range and the UNBALANCE light goes out.

d. Proceed as follows, repeating step c wherever the symbol [c] appears: SET ZERO, START, [c].

e. Change the "unknown" to 1000 pF, START, [c]. SET ZERO, START, [c].

f. Repeat step e for "unknown" capacitors of 100 pF and 10 pF.

g. Switch to the TRACKING mode and verify that the capacitance readout responds as your hand moves near or touches the small measured capacitor.

h. Switch the mode to VARIABLE MEASUREMENT RATE and set the RATE control to FAST.

Verify the same behavior as before. However, by turning the RATE control ccw to SLOW, verify that the changes in readout occur in jumps.

i. Switch the mode to TESTS and RATE to a medium setting. Verify that the numerical displays advance or retreat as follows: (press the SET ZERO button to unbalance the bridge initially)

TESTS 1 – C forward.

TESTS 2 – C reverse.

TESTS 3 – G forward.

TESTS 4 – G reverse.

TESTS 5 – Balance, i.e., the bridge counts toward balance as in the TRACKING mode except that the counting rate is slower, as determined by RATE.

5.2.7 Sensitivity.

This checks for normal functioning of the control. (Refer to para. 3.10.) Use the setup of the preceding paragraph, with a 100-pF capacitor connected, controls at standard settings.

a. With the RANGE switch on 200 pF, press START. Record the C measurement.

b. Make the bridge count up by switching temporarily to a lower range and pressing START. Repeat step a.

c. Make the bridge count down, similarly, on a higher range. Repeat step a.

d. Verify that these C measurements are within ±1 count (.001 pF).

e. Turn the SENSITIVITY control ccw to MIN. Repeat the above procedure, steps b and c. Verify that these C measurements differ by ***approximately*** ±50 counts (.050 pF).

f. Return the SENSITIVITY control to MAX.

5.3 DISASSEMBLY.

5.3.1 Knobs.

CAUTION

Do not use a screwdriver or other instrument to pry off the knob if it is tight. Do not lose the spring clip in the knob when it is removed.

To remove the knob from a front-panel control, either to replace one that has been damaged or to replace the associated control, proceed as follows:

a. Grasp the knob firmly with dry fingers close to the panel and pull the knob straight away from panel.

b. Observe the position of setscrew in bushing when the control is fully ccw.

c. Release the setscrew with an Allen wrench; pull the bushing off the shaft.

NOTE

To separate the bushing from the knob, if for any reason they should be combined off of the shaft, drive a machine tap a turn or two into the bushing to provide sufficient grip for easy separation. If the retention spring in the knob falls out, reinstall it in the interior notch with the small slit in the inner diameter of the wall.

To replace a knob:

a. Slip bushing on shaft and rotate to correct position as observed in disassembly of knob.

b. Keep bushing away from panel by at least the thickness of a filing card. Pull it out farther if necessary to prevent tip of shaft from protruding.

c. Tighten the setscrew in the bushing.

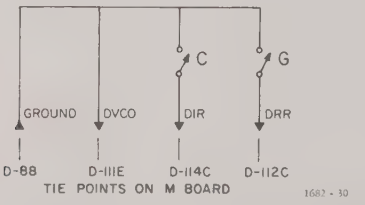

Figure 5-1. Direction controller schematic diagram. Assemble 2 toggle switches on a small panel or box. Label them C and G, forward (closed) and reverse (open). Provide 4 wires as shown, 2 or 3 ft. long, each preferably soldered to a socket clip for convenience in connecting to pins on the M board.

d. Place knob on bushing with retention spring opposite setscrew.

e. Push knob on until it bottoms and pull it lightly, to check that the retention spring is seated in groove in bushing.

NOTE

Keep POWER OFF during disassembly or reassembly.

5.3.2 Cabinet Removal. Figure 2-4.

To remove the bench-model cabinet, first set the instrument in the horizontal position, free of unnecessary cables, and proceed as follows:

a. Remove the 4 dress-panel screws (A) accessible through holes in the handles.

b. With caution not to let the instrument drop out of its cabinet, turn it face down to rest on the handles.

c. Pull the cabinet up and off. Carefully return the instrument to a horizontal position.

5.3.3 Visual Display Parts. Figures 5-2, 5-6.

Numerical Indicator Tubes. Pull each tube out vertically for replacement. It is ***not*** necessary to remove the Z-board assembly for this or the following procedure.

Unit Indicator Lamps. Each indicator assembly contains 1 or 2 spare bulbs, originally. To replace a spent bulb:

a. Pull the indicator assembly out vertically.

b. Remove 2 screws and one side of the assembly.

c. Remove the etched board from its slot.

d. Unsolder the defective lamp and substitute a new one.

5.3.4 Shield Covers.

Each cover spans the full width of the instrument. The bottom one has a set of holes for access to the capacitance-standards trimming screws and is somewhat smaller than the top one. Remove a screw in each corner and lift either cover for access to F, J, K, L, O, and S boards.

NOTE

Shield covers must be in place during calibration; bridge accuracy is lost while they are off. Use only a nonconducting screw at the front left corner of the top cover; it must not be grounded over the 0 board.

5.3.5 Most-Easily Removed Boards. Figure 5-2.

The D, E, I, O, P, and R boards are removable as follows: Rotate the 2 locking tabs upward and pull a board straight out of its connector. Figure 5-4 shows the E board partly removed.

To replace a board, orient it correctly and check that the guides align the board-edge contacts exactly at the socket contacts. (Early production instruments, ID number 0100, require manual guidance for this alignment.)

Start the board into its connector, engage the locking tabs, and push them closed while seating the board firmly in place.

5.3.6 Extenders. **Figure 5-4.**

For working access to many of the boards (D, E, I, O, P, R, V, Z) an extender may be used. Replace the board with the extender, then plug the board into its socket. Two extender boards, side-by-side, are needed for the Z board.

Alignment of board-edge contacts with socket contacts is particularly important when extenders are used; orient the board correctly and align the contacts accurately for completion of all circuits through the extender.

5.3.7 The Z-Board Assembly. **Figures 5-5, 5-6.**

WARNING

Even though instrument power is off, the voltage on this wire may be hazardous:

a. Unplug the 250-V wire from H-AT1 and touch the metal tip to chassis.

b. Remove 2 screws at each side of the instrument: A, A in the figure.

NOTE

Some instruments have only one screw A, where the figure shows two. After removing A, unclamp the block into which it was threaded, by loosening a screw above. In reassembly, tighten the screw from above last.

c. Remove the nearby I and R boards for easier access.

d. Remove the Z board similarly (although the process is encumbered). Lift about ½ in. directly up and then farther holding the assembly back so the molded control-knob recess will not snag on the display window. Lift carefully until free.

e. Remove 2 screws from the H board and pull it forward from its socket on the Z board.

f. Unplug the numerical readout tubes or unit indicator assemblies if desired.

NOTE

These can be removed very easily with the Z-board assembly in place. Disassemble them as described in para. 5.3.3.

g. Knob removal is described in para. 5.3.1.

h. When replacing the Z board, carefully follow the alignment procedure of para. 5.3.5.

5.3.8 Screw-Fastened Boards. **Figures 5-2, 5-5.**

V Board. Remove 2 screws at the upper corners of the V board and pull it out of its socket.

S Board. Remove the S board similarly. If this must be operated in a partially removed position, remove 2 screws holding its socket to the side of the instrument. Tilt the board up without unplugging it.

CAUTION

Do not remove the J, K, or L boards without good reason. There are several high-frequency cables to be unsoldered and reconnected.

J Board. Remove 2 screws from the base brackets of the J board, and withdraw the board partially. For complete removal, carefully unsolder the cables as required, tagging them for proper replacement.

K; L Boards. Unplug or unsolder the single wires from capacitance standards to corresponding pins on K and L boards before removing them as above.

5.4 OUTLINE OF ADJUSTMENTS.

This paragraph lists adjustments in alpha-numeric order, giving their purposes. Instructions for setting most of these are included in para. 3.7.2, 5.5, and 5.6.

A-C20. Test-fixture capacitance compensation for 20-pF range. Rear panel. Figure 5-3.

A-C23. Test-fixture capacitance compensation for 2000-pF range. Rear panel. Figure 5-3. See also Figure 6-3 for shaft position at rear.

A-C24. Test-fixture capacitance compensation for 200-pF range. Rear panel. Figure 5-3.

A-C25. Padder for A-C24. Used to shift or extend the effective range of its compensation. Bottom. Figure 5-3.

D-R7. Quadrature reference phase adjustment in phase detector (G-error sampler; affects DRR). D board. Figure 5-4.

D-R21. Reference phase adjustment in phase detector (C-error sampler; affects DIR). D board. Figure 5-4.

D-R67. Threshold adjustment for balance recognition (affects $\overline{\text{DBAL}}$) D board. Figure 5-4.

D-R97. Error-amplifier symmetry adjustment (affects DRR and DIR) D board. Figure 5-4.

K-R34. Phase compensation for 20-pF range. K board (left). Figure 5-2.

O-T1. Oscillator feedback-transformer tuning. O board. Set for maximum amplitude. Figure 5-4.

O-T2. Oscillator output-transformer. O board. Not used as an adjustment. Figure 5-4.

S-T1. Preamplifier coupling-transformer tuning. S Board. Figure 5-5.

S-T2. Preamplifier output-transformer tuning. S Board. Figure 5-5.

T-R9. Phase compensation for 2000-pF range. Left side panel. Figure 5-7.

T-R10. Phase compensation for 20-nF range. Left side panel. Figure 5-7.

V-R18. Voltage regulator, −15-V level. V board. Figure 5-2.

V-R34. Voltage regulator, +10-V level. V board. Figure 5-2.

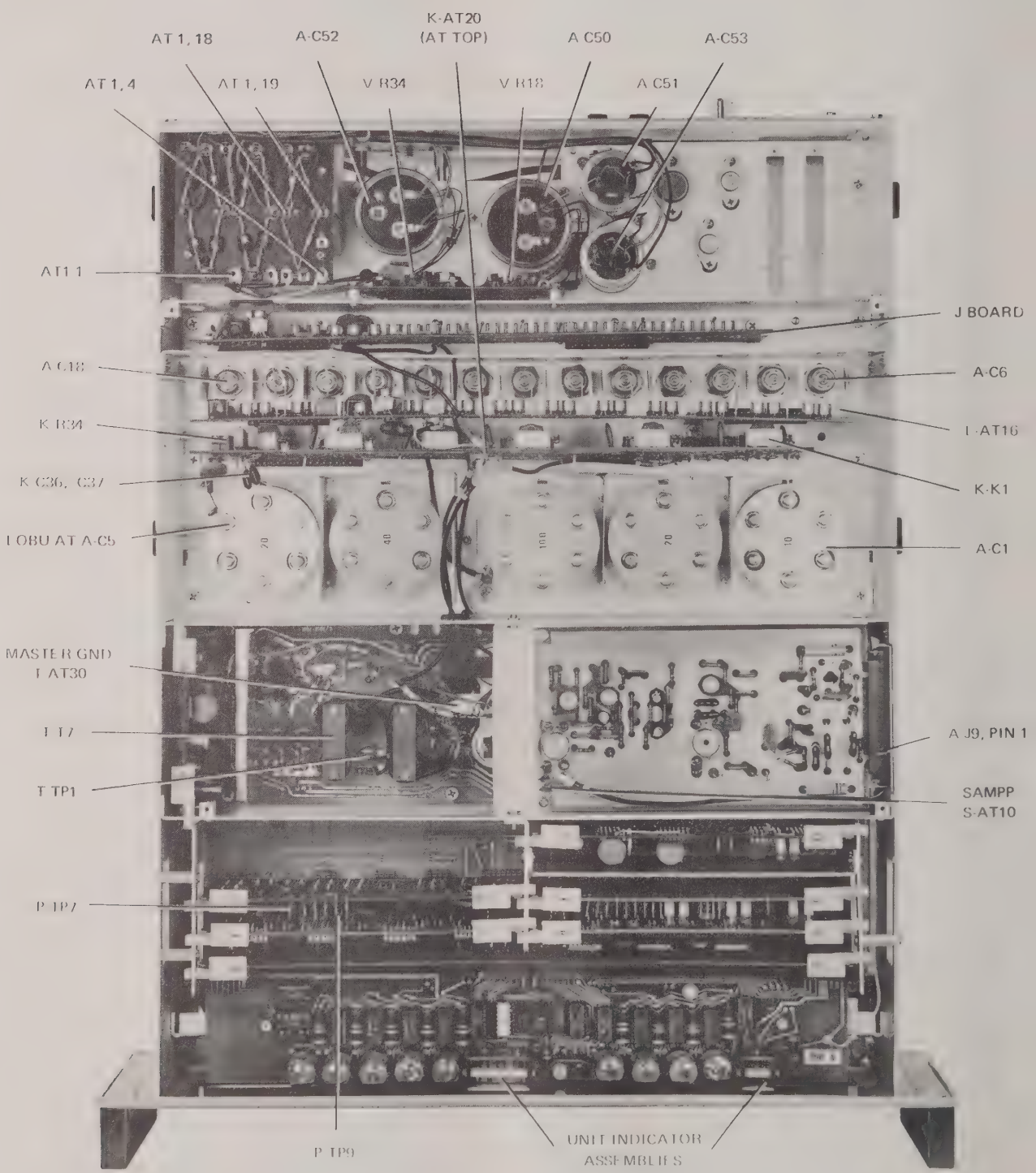

Figure 5-2. Interior, top view.

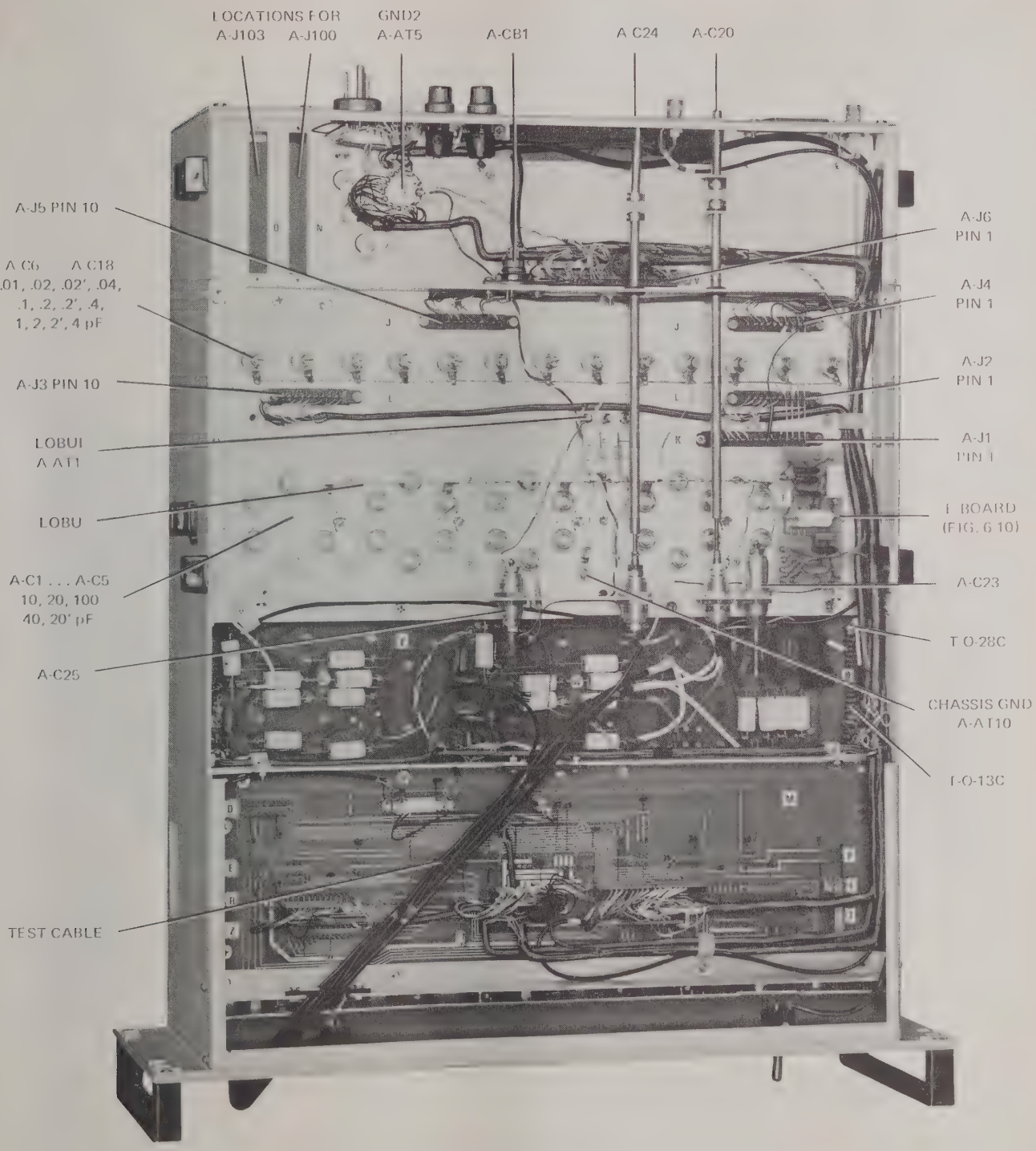

Figure 5-3. Interior, bottom view. Refer to Figure 5-7 for T- and M-board details.

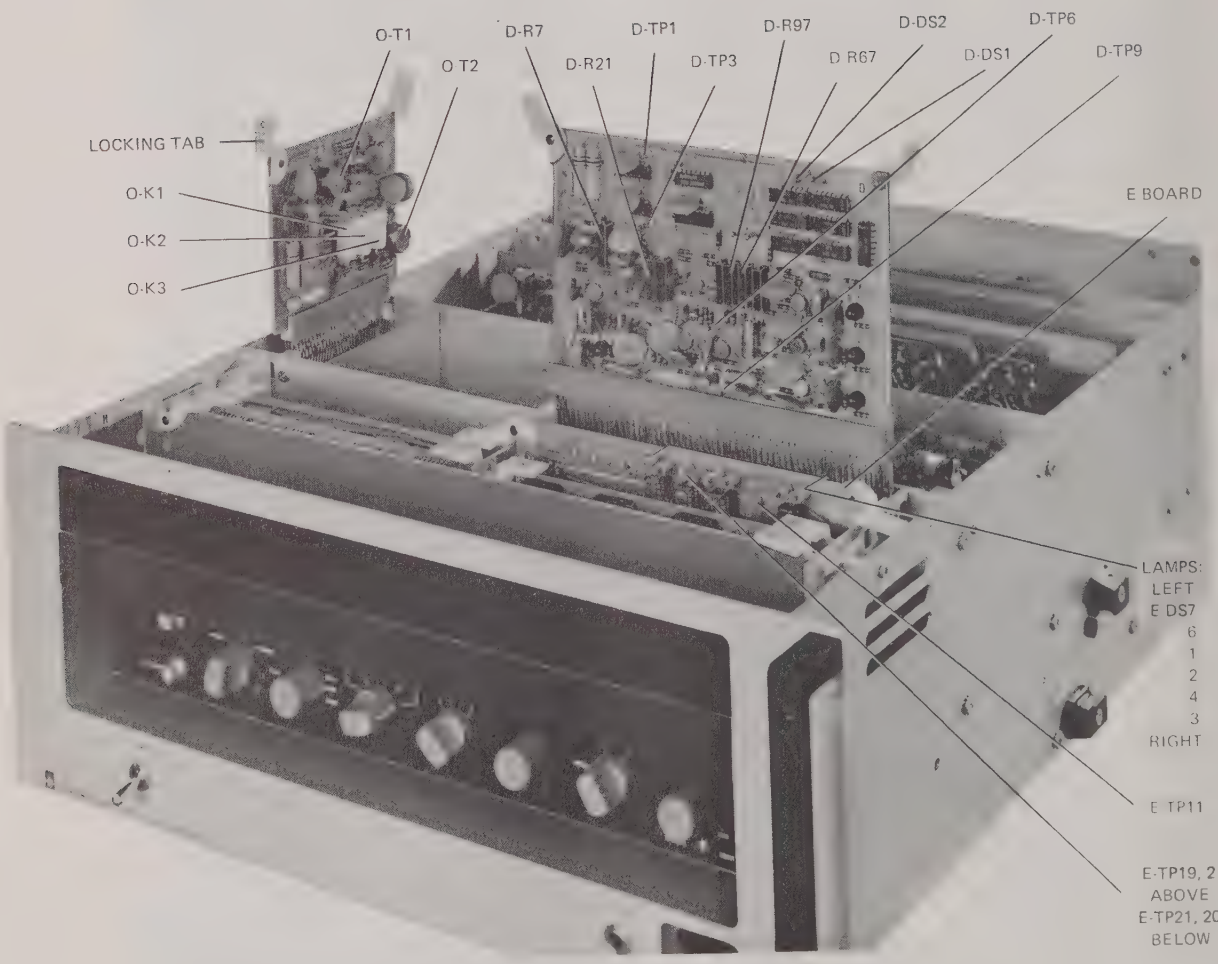

Figure 5-4. Extension of O and D boards for access under operating conditions. E board partially removed (non-operating). Refer to table 5-10 for key to state-indicator lamps.

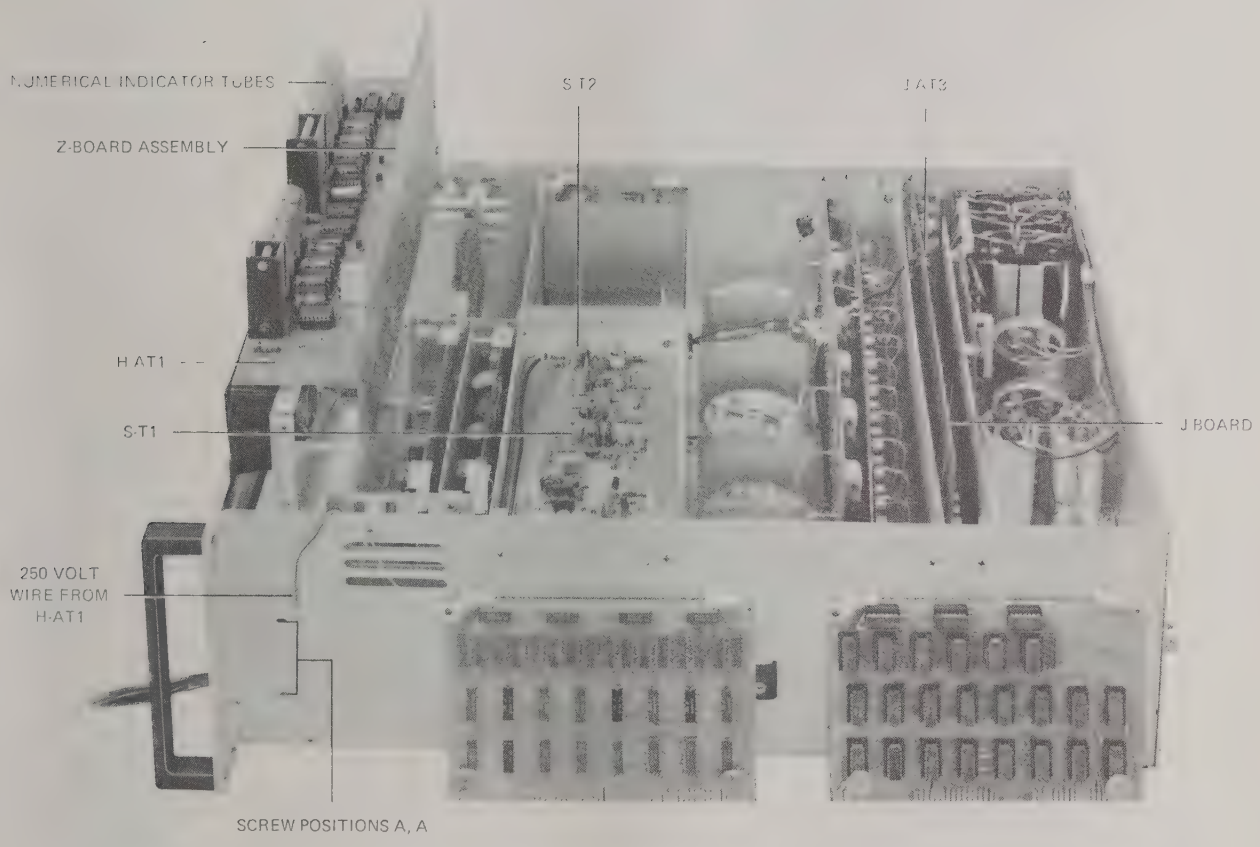

Figure 5-5. Removal of Z-board assembly (Z and H boards, indicators, and front-panel controls). I and R boards are set aside to make room.

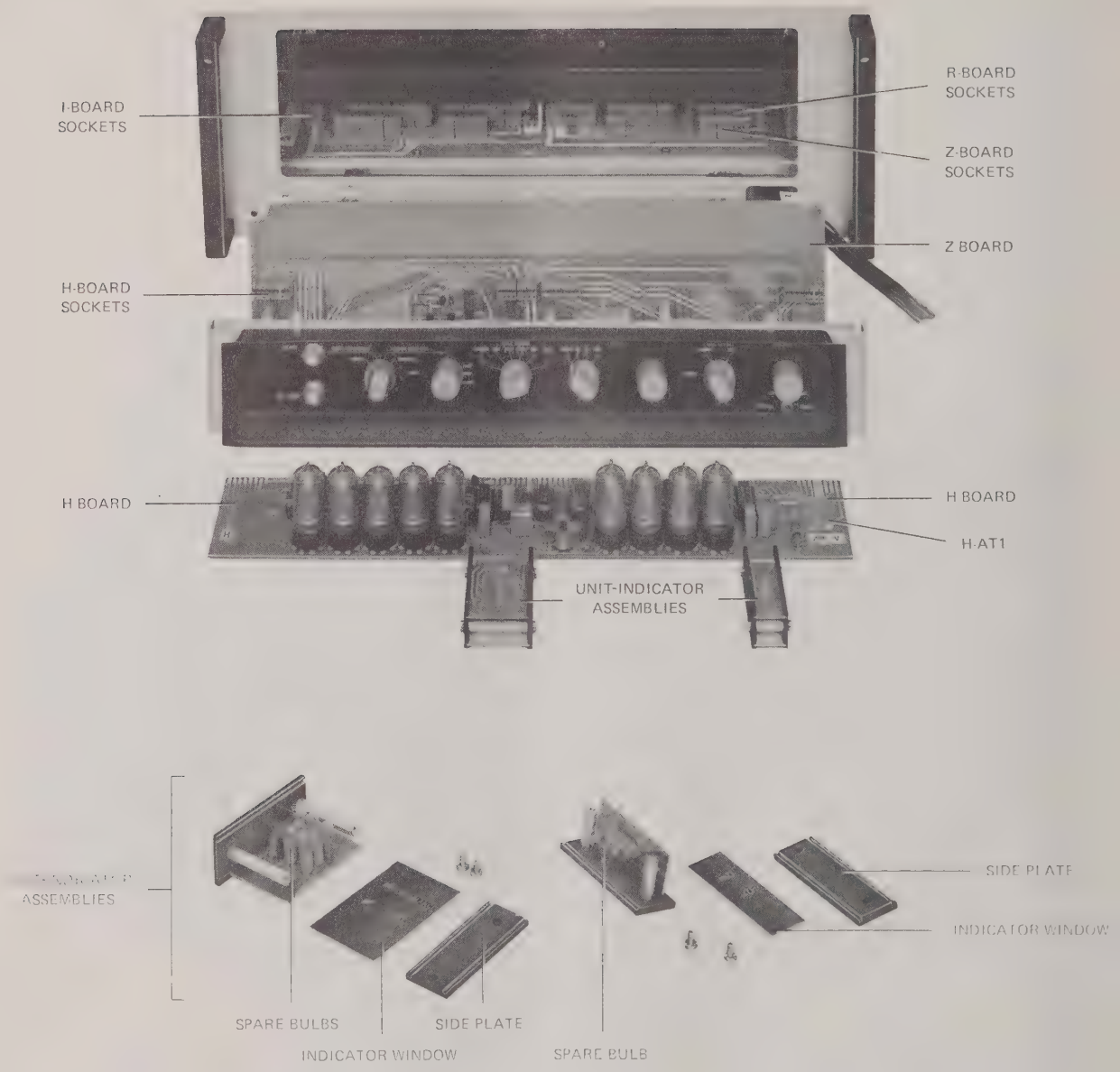

Figure 5-6. Removal of H board from Z-board assembly. Removal and disassembly of unit indicators.

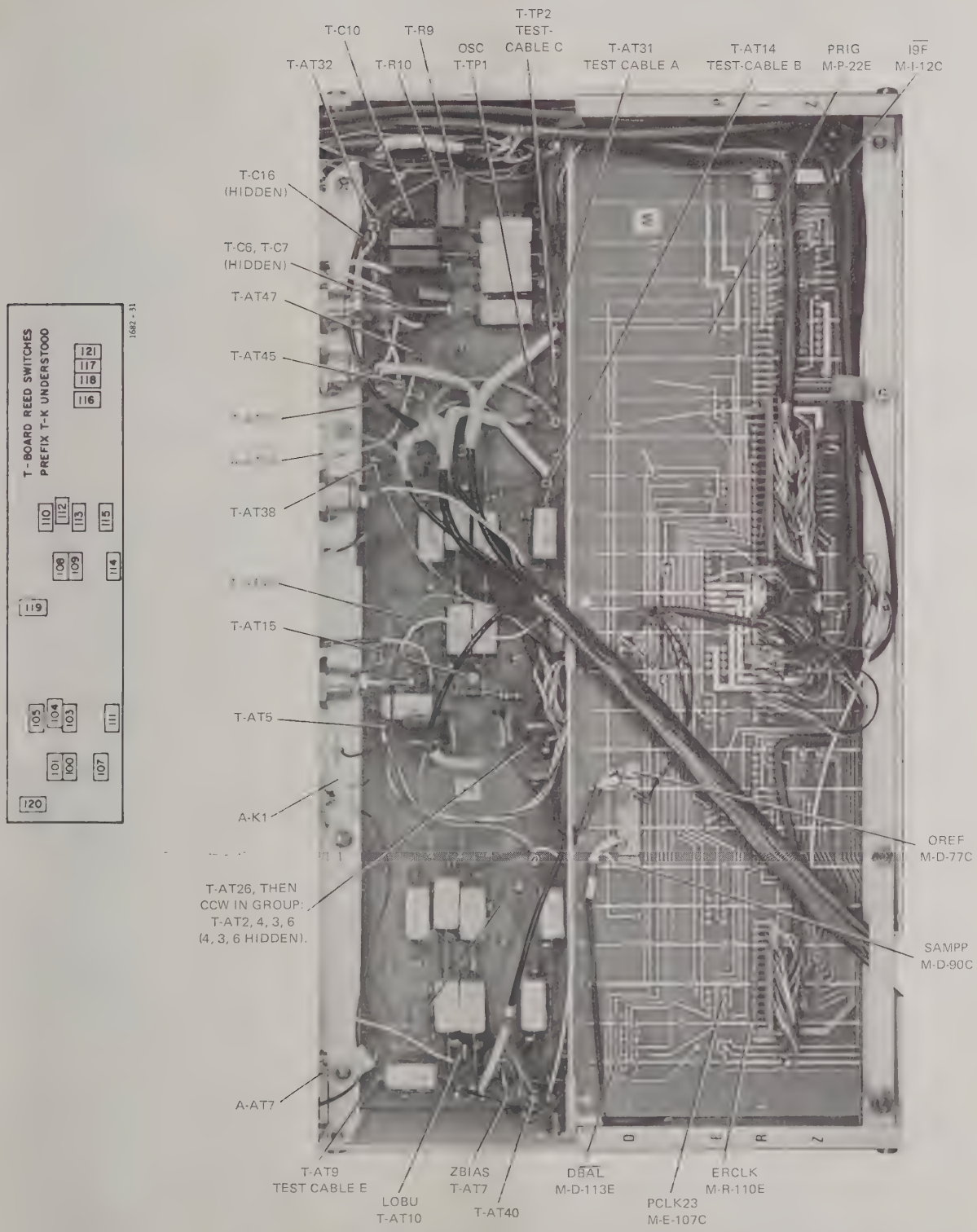

Figure 5-7. Detailed bottom view of T and M boards. The line drawing identifies individual reed switches.

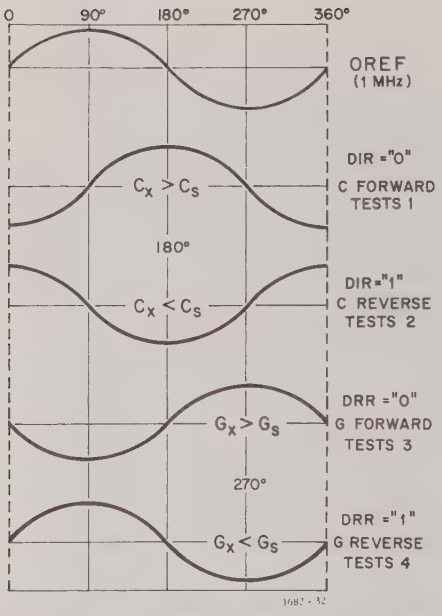

Figure 5-8. SAMPP waveform interpretation. Conditions listed at right all lead toward balance.

5.5 PHASE- AND BALANCE-DETECTOR ADJUSTMENTS.

5.5.1 Setup and Preliminary Checks.

a. Remove the cabinet (para. 5.3.2) and set the instrument on its right side (use a block at the rear for stability). Access will be required to the V and M boards (bottom) and D board (top). D need not be extended.

b. Verify that the power-supply voltages are correct. Pertinent adjustments are tabulated; refer to Table 5-5. The reference is GND 2 (A-AT5 Figure 5-3) or the main chassis.

c. Use standard settings except switch mode to TESTS 5.

NOTE

Scope must ***not*** be grounded through power cord or any other connection except channel-1-probe ground return.

d. Obtain a display of OREF, a 1-MHz, 640-mV (pk-pk) sine wave, as follows: Connect the channel-1 scope probe to OREF, at M-D-77C, Figure 5-7. Connect the probe ground to the bridge chassis (note above). Connect channel 1 trigger out to main time base (B) trigger input. Set the time/cm switches to 0.1 μs/cm, time base A to cal, horizontal display to A delayed, the delay-time multiplier to a large number. Use the main time base (B) variable delay time control to set the negative-going zero crossing of OREF (the 180° reference) at center of scope screen. Set preamp mode to alternate for display of both channels.

NOTE

The reference waveform appears in the schematic Figure 6-7, at TP-10. The vertical dashed line represents 0° phase. On other waveforms similar dashed lines are the same instant in time.

e. Connect the 1682-P3 Test Fixture to the test cable. Install 2 874-EL elbows, facing the connector side, on the fixture. Place the 1422-CL variable capacitor near the table edge and plug in the elbows so that the test cable leads up from below table level to the test fixture. There must be no sharp bends in the test cable.

Table 5-5

POWER-SUPPLY VOLTAGES

A-J6 (Figure 5-3)	A-J1 (Figure 5-3)	Acceptable Range min	Acceptable Range max	Adjustment (Figure 5-2)
10	3C	4.75	5.25	(V-R18)
30	2B	9.5	10.5	V-R34
19	1A	14.25	15.75	(V-R18)
27	4D	−14.25	−15.75	V-R18

5.5.2 Phase-Detector Reference Adjustments. Figure 5-4.

Connect the channel-2 scope probe to each test point listed below and make the corresponding adjustments if necessary. The waveforms are square waves, 0 to +5 V.

C-error sampler. Look at D-TP3 waveform; adjust D-R21. Make sure the "1" to "0" transition occurs at 360° (OREF positive-going zero crossing) within ±15°.

G-error sampler. Look at D-TP1 waveform; adjust D-R7. Make sure the "1" to "0" transition occurs at 270° (OREF negative peak) within ±15°.

5.5.3 SAMPP Waveform. Figure 5-8.

Connect to SAMPP at M-D-90C (Figure 5-7) using the channel-2 probe. OREF, at M-D-77C, is used to trigger the scope time base, as described before.

The bridge error signal should be interpreted by noticing its deflection at 180° and 270° with respect to OREF, as shown in the figure. The dashed line at 0° is a phase-reference designation, which appears also in schematic Figure 6-7. Notice that there is no phase relationship between these 1-MHz waveforms and the lower-frequency clock signals of Figure 4-2. It is convenient to think of Cx as pushing the waveform up or down at 180°, Gx at 270°. Notice that C balance exists when there is a zero crossing at 180°, G balance at 270°. (SAMPP has no dc component.)

You can use the TESTS modes to make SAMPP essentially zero, to arrive at a perfect balance with a fixed "unknown" capacitor, or to set in a certain amount of unbalance. Choose the mode desired (referring to Figure 5-8) and turn the RATE control to SLOW. Return it quickly to STOP as soon as the desired change in SAMPP has been realized. Do not rotate the mode switch to (or

past) the TRACKING position if the above setting is to be preserved.

5.5.4 Phase-Detector Symmetry. Figure 5-9.

Provide the specified level of error voltage and adjust the first stage of the error amplifier that drives the phase detectors, as follows:

a. Look at SAMPP, found at M-D-90E (or D-TP9) via channel 2, as in para. 5.5.3. Use maximum scope sensitivity, 5 mV/cm.

b. Set the 1422-CL variable capacitor to 70 pF = Cx. Bring the bridge to balance by switching to SINGLE MEASUREMENT mode and pressing START. Observe the effect of changing Cs a few pF; see how small SAMPP can be made. The G balance can be automatically reestablished by pressing START again, preferably with Cx slightly unbalanced. Do this several times and stop when G is well balanced (SAMPP < 10 mV pk). If this method is unsatisfactory, use the procedure in paragraph 5.5.3.

c. Look at D-TP6 via channel 2. (It can be reached with the scope probe without extending the D board.) Figure 5-4.

d. Unbalance the bridge by 0.2 pF. If the error SAMPP is minimum at 71.5 pF for example, set Cx to 71.3 pF. Verify that the waveform is trapezoidal with rounded corners, as shown in Figure 5-9. Set the channel-2 position control so that A=B (top and bottom of the waveform equidistant from the scope centerline).

e. Verify that the waveform is symmetrical (C = D within 5%) or adjust D-R97 for that symmetry.

5.5.5 Balance-Recognition Threshold.

Adjust the reference level to which SAMPP is compared in determining $\overline{\text{DBAL}}$ at MAX SENSITIVITY as follows:

a. Set the mode switch to VARIABLE MEASUREMENT RATE, the RATE control to about 1 or 1.5 seconds per measurement. (The scope is not needed, but may be used to monitor $\overline{\text{DBAL}}$ at M-D-113E, Figure 5-7.)

NOTE

If the measuring cycle cannot be detected by seeing periodic, faint flickering and occasional 1-digit changes in the least-significant C digit, accentuate these effects by slow rotation of the variable capacitor dial. ($\overline{\text{DBAL}}$ on the scope is "0", except "1" very briefly once during each measuring cycle.)

b. Turn D-R67 (Figure 5-4) ccw about 15 turns, or more if necessary to produce hunting. Hunting occurs when the bridge changes direction endlessly (without recognizing balance) until abortion. Hunting is indicated by the measuring cycle which was about 1 s now being 3 s, with the flicker mentioned in the note above now lasting about 2 s. ($\overline{\text{DBAL}}$ on the scope is now "1" for 2 s per cycle.)

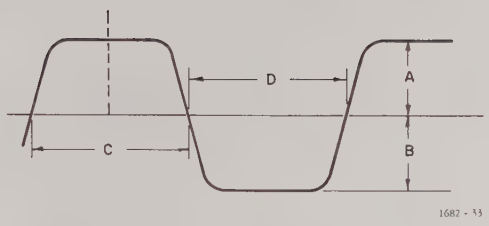

Figure 5-9. Error-signal waveform, at D-TP6 in the phase detector, set to the proper amplitude for symmetry adjustment.

NOTE

If the bridge were hunting in step a, no setting of the RATE control could bring the measurement cycle down to 1-s duration.

c. Check that the SENSITIVITY control is fully cw, at MAX.

d. Turn D-R67 cw until hunting stops, and then 5 turns farther cw. If hunting persists, refer to para. 5.7.7.

NOTE

The dc potential at D-IC17 pin 2 should now be about +10 mV. Hunting occurs when it is negative.

5.6 RECALIBRATION.

5.6.1 General.

Recalibration is essentially trimming the standard capacitors to correct values and resetting certain compensations. However, paragraph 5.6 includes other checks and adjustments pertinent to bridge accuracy, all of which should be included in a recalibration procedure to rejuvenate the instrument after years of use, or following repairs that affect accuracy.

Recalibrate the bridge only if it is in good repair. For example, in many cases it is best to check for proper operation of T-board reed switches (para. 5.7.6) before recalibration.

CAUTION

If the adjustment of an internal standard or zero-setting capacitor apparently requires the adjusting screw to be turned fully cw, do not leave it there. To avoid a possible short circuit, set it at least 1/2 turn ccw. Use a non-metallic wand with a small metal blade as a screwdriver for making most of the adjustments. It has negligible effect on stray capacitance; it is unlikely to break fragile adjusting screws.

Table 5-6

POWER-SUPPLY CHECK POINTS
ON F, K, O, and T BOARDS

Reference Figure	Dc Voltages (±5%) +5	+10	+15	−15
5-3	——	——	F-AT5	——
	A-J1, 3	A-J1, 2	A-J1, 1	A-J1, 4
	——	——	T-0-13C	T-0-14C
5-7	——	——	T-AT6	T-AT46
	——	——	T-AT38	——

Table 5-7

POINTS WHERE ZRRO-SERIES SIGNALS
ON F, K, O, AND T BOARDS ARE "0".

Reference Figure	If the RANGE is: 20 pF	200 pF	2000 pF	20 nF
5-3	F-AT2	F-AT3	F-AT4	——
	A-J1, 6	A-J1, 5	——	——
	T-0-7C	T-0-8C	T-0-10C	T-0-11C
5-7	T-AT2	T-AT3	T-AT4	T-AT5

NOTE

Clean the GR900® connectors (on the 1682-P2 Test Fixture and the coaxial capacitance standards) using the GR 900-TOC cleaning kit, before proceding to recalibrate. However, do ***not*** use it on connectors with polystyrene beads.

5.6.2 Preliminary Checks, D-board Adjustments, and Setup.

a. Complete the procedures of para. 5.5, including phase-detector and balance-detector adjustments.

b. Verify the presence of power-supply voltages and ZRRO-series signals at the F, K, O, and T boards. Table 5-6 lists dc voltages. At each terminal in Table 5-7 verify that the voltage is "0" (under 0.4 V) when the RANGE switch is in the indicated position, and "1" (+3 to +5.5 V) in the other 3 fixed-range positions.

c. Switch POWER OFF and remove the D board.

d. Attach a 100-Ω resistor (±5%, 1/4 W) across the output of the S board as follows: Use Berg socket clips for convenience, or tack-solder. Connect the resistor between SAMPP (M-D-90C) and the nearby ground (M-D-87C, Figure 5-7).

e. Connect the manual direction controller similarly to the 4 tie points given in Figure 5-1. Turn POWER on.

f. For ***manual operation***, manipulate the bridge counters as follows: Select C or G with the mode switch (TESTS 2 or TESTS 3 respectively); select direction of count with the corresponding switch on the direction controller, control speed or STOP counting with the RATE control. Press the SET ZERO button for a zero readout.

g. Connect the 1682-P3 Test Fixture to the test cable. Connect to the 1422-CL variable capacitor, using elbows and observing precautions as in para. 5.5.1.

h. Set up the scope as described there. Set the time base to 1 μs/cm, triggered from channel 1, which carries OREF. Set the preamp mode to ALT.

NOTE

Scope must ***not*** be grounded through the power cord or any other connection except channel-1 probe ground return; connect that to the 1682 chassis.

5.6.3 Standard-Switching Checkout. **Figure 5-2.**

The following procedure verifies that the C standards are properly switched by the IQ-series signals, and the G standards by the RQ-series. The BCD code of those signals (Table 2-4) specifies combinations of 1, 2, 4, and 8 for each decimal digit of the counters. However, the standards are provided in the 1, 2, 4, 2′ sequence. Every time an 8 is specified, the 2, 4, and 2′ standards are switched in simultaneously.

a. Turn the mode switch to TESTS 1.

b. Connect the channel-2 probe to L-AT16 (Figure 5-2), the L-board pin where a wire leads to the right-most capacitor, A-C6. Make the C counter go slowly forward and verify that this terminal receives a 1-MHz signal every time the 5th digit of the C readout is an odd number, and no signal when that is even. Compare those observations with the first row in Table 5-8.

NOTE

The amplitude of the signal is not important to this checkout, but should be about half the amplitude of OSC, found at T-TP1 (Figure 5-7).

c. Proceed through Table 5-8 with a complete checkout. The test points are arranged in the table in this order: right-to-left along the L board and then the K board (even though the spill digit, midway on the K board, might logically be left until the last). Each time the probe is moved to a new test position, press SET ZERO to establish a consistent starting point. Each time the test advances to a lower-numbered (more significant) digit, turn the RATE control cw to a convenient counting rate.

d. Connect the channel-2 probe to J-TP1 (the junction of R83 and R84; Figures 5-5 and 6-18) and start the G counter forward. Verify that the signal at TP1 is a 1-MHz sine wave that changes level with the least-significant (4th) G digit, starting with zero at 0 readout. Set the RATE control to FAST and check that the 9 steps are apparently uniform.

Table 5-8

C-STANDARDS SWITCHING SEQUENCE

A 1-MHz sine wave is present (1) or absent (0)

Probe at	Standard C designation and value, pF		Readout digit	when that digit is 0	1	2	3	4	5	6	7	8	9
L-AT16	A-C6	.01	5th	0	1	0	1	0	1	0	1	0	1
15	7	.02		0	0	1	1	0	0	1	1	1	1
13	8	.02′		0	0	0	0	0	0	0	0	1	1
14	9	.04		0	0	0	0	1	1	1	1	1	1
L-AT12	A-C10	0.1	4th	0	1	0	1	0	1	0	1	0	1
11	11	0.2		0	0	1	1	0	0	1	1	1	1
9	12	0.2′		0	0	0	0	0	0	0	0	1	1
10	13	0.4		0	0	0	0	1	1	1	1	1	1
L-AT8	A-C14	1	3rd	0	1	0	1	0	1	0	1	0	1
7	15	2		0	0	1	1	0	0	1	1	1	1
5	16	2′		0	0	0	0	0	0	0	0	1	1
6	17 & 18	4		0	0	0	0	1	1	1	1	1	1
K-AT11	A-C1	10	2nd	0	1	0	1	0	1	0	1	0	1
12	2	20	2nd	0	0	1	1	0	0	1	1	1	1
15	3	100	1st	0	1		—— spill only ——						
13	4	40	2nd	0	0	0	0	1	1	1	1	1	1
14	5	20′	2nd	0	0	0	0	0	0	0	0	1	1

e. Similarly, check that the signal at J-TP2 (the junction of R81 and R82) changes level with the 3rd digit of the G readout. There is also a family of intermediate changes that follow the 4th digit, but those are less pronounced.

f. Similarly, check that the signal at J-TP3 (the junction of R79 and R80) changes level with the 2nd digit.

g. Check that the signal at the lower end of J-R66 (Q14 emitter) is absent when the 1st (spill) digit is 0, present when it is 1. If this check point is difficult to reach, check instead that the digital signal R$\overline{Q}$0, at A-J4 pin 7 (Figure 5-3) is "1" for spill digit 0, "0" for spill digit 1.

5.6.4 Oscillator Output.

This checks the oscillator output level, which is switched depending on range:

a. Connect the channel-2 probe to OSC at T-TP1 (or T-AT23, Figure 5-10). The waveform there should be 180° out of phase with OREF; the period 1 μs.

b. Verify that the amplitude of OSC is within ±10% of these values, mV pk-pk: 1560, 310, 155, 155, respectively, as the RANGE switch is set to 20, 200, 2000 pF, and 20 nF.

c. If necessary, adjust O-T1 and O-T2 (Figure 5-4) carefully to maximize the oscillator output on all ranges. If the ratios between ranges are abnormal, analyze the trouble with the help of para. 5.7.7 and 5.7.8.

5.6.5 Preamplifier Phase and Gain. **Figure 5-5.**

Check. This is to verify that the preamplifier has satisfactory gain and phase at the oscillator frequency:

a. Connect the channel-2 probe to the preamplifier output SAMPP at M-D-90C.

b. Manually set the bridge readout to 100.00 pF, 000.0 $\mu\mho$.

c. Balance the bridge by bringing the variable capacitor Cx to 100 pF (more or less, as required) and manually advancing the G counter as far as necessary (para. 5.6.2).

d. Verify that phase is 270° ±5°, evaluated as follows: (see Figure 5-8.) Rock the variable capacitor rapidly through balance with a rhythmic twist of your wrist. Notice the X formed on the scope between SAMPP waveforms of Cx > Cs and Cx < Cs. (These cross at 0 volts only if G is perfectly balanced.) The center of the X indicates the phase.

e. Verify that gain is such that SAMPP changes 100 ± 20 mV for exactly 0.10 pF change in Cx, near balance. Measure this at the 180-degree part of the SAMPP waveform.

Adjust. If the preceding check is negative, set the gain and phase as follows:

a. Press SET ZERO. (Cx is still about 100 pF.) Move the channel-2 probe as required.

b. Tune S-T1 for maximum signal at S-AT8. (near T1, Figure 6-35).

c. Tune S-T2 for maximum SAMPP signal at M-D-90C.

d. Manually set the bridge readout to 100.00 pF, 000.0 $\mu\mho$. Balance the bridge by adjusting the variable capacitor Cx and by manually advancing the G readout as far as necessary.

e. Set the C readout up 10 counts, to 100.10 pF. Measure phase as described in the check, step d.

f. Set the phase to 270° ±5° by tuning S-T1 only. (This adjustment is sensitive.)

g. Reduce amplitude of SAMPP, if necessary, to 200 mV pk-pk ±20%, by tuning S-T2 only.

h. Repeat steps f and g, if necessary to meet both phase and gain requirements.

5.6.6 Ratio Compensation.

This is to check on the fine compensation for effects of test-cable parameters on the 1:1 ratio transformers. The compensation circuitry is on the K and F boards.

a. Install tee connectors in place of the elbows between the test fixture and variable capacitor. Plug binding-post adaptors into the open connectors of the tees.

NOTE

It is now important to keep hands and other conductors away from the exposed bridge terminals, when making a balance.

b. Return the G readout to zero; keep the C readout at 100.00 pF.

c. Measure SAMPP.G-O.C-100, i.e., the error signal level at zero conductance while balancing 100 pF. Do this while the variable capacitor is set for a zero crossing at 180°. Measure the total amplitude (at 90° and 270°) in mV pk-pk (+ if the waveform is like "Gx > Gs" of Figure 5-8, – if like "Gx < Gs").

d. Simulate an ideal 100-$\mu\mho$ balance as follows: Obtain a matched pair of 10-kΩ resistors, described in Table 5-2 under "conductance references." Connect one across the test fixture, at the binding posts installed in step a. Connect the other between TOSCS (at K-AT20, Figure 5-2, where several coaxial cables connect to a common circuit) and LOBU (at the frame of A-C5). For the latter, use clip leads no longer than 2 in. max.

e. Measure SAMPP.G-100.C-100, i.e., the error signal level while both Gx and Gs are offset 100 $\mu\mho$, while balancing 100 pF. As in step c, reset the variable capacitor for a zero crossing at 180°, before reading mV pk-pk.

f. Verify that SAMPP.G-100.C-100 = SAMPP.G-O.C-100, within ±32 mV, which is equivalent to 1 count of a G measurement. Otherwise, it may be necessary to change the value of K-C35.

g. Reset the C readout to 80.00 pF, keeping the G readout at zero. Disconnect the pair of resistors. Repeat steps c, d, e. Verify that SAMPP.G-100.C-80 = SAMPP.G-O.C-80 as in step f.

h. Continue the process with C = 40, 20, and finally 10 pF. Each check should be valid within ±32 mV (for peak-to-peak measurements). If the checks get progressively worse for smaller values of C, look first for trouble in the compensation on the F board. (Refer to para. 5.7.9.)

i. Remove the pair of 10-kΩ resistors.

5.6.7 Capacitance Standards Recalibration.

General. The 17 internal standards are recalibrated as follows, on the range utilizing 1:1 ratios in the ratio transformers, against the precision variable capacitor. Subsequently, a thorough check is made against coaxial capacitance standards (with accuracy traceable to the National Bureau of Standards) on each range. Range compensation is then readjusted if necessary. A pertinent service section is para. 5.7.9.

NOTE

Avoid any unnecessary flexing or repositioning of the test cable and test fixture during the entire recalibration and checking process. Use hardware supplied with each fixture to clamp the cable about 3 or 4 in. behind the fixture.

Setup. Proceed as follows:

a. Reinstall the top and bottom shield covers (with POWER OFF temporarily). See NOTE in para 5.3.4.

b. Remove the tees from the 1682-P3 Test Fixture and install elbows again, ready for connection to the variable capacitor as before. Otherwise, the setup is unchanged. Settings are standard (Table 5-1) except mode is TESTS 2 or 3. The scope displays OREF in channel 1, which triggers the sweep. The 180°—position is in the center of the scope face. Channel 2 displays SAMPP, which is interpreted by Figure 5-8. The D board is out, and all balancing is manually controlled.

c. Make the rear-panel zero adjustment as follows: Press SET ZERO, and see that both readouts are zero. Adjust A-C24 for perfect C balance (zero crossing at 180°). If the range of A-C24 is not adequate, adjust A-C25 (Figure 5-3).

d. Prepare a calibration table for the 1422-CL Precision Capacitor. Use the format of Table 5-9, which has blank columns so you can make a copy and fill it in with data uniquely applicable to your capacitor.

Column A is a general correction term for this type of capacitor used with this bridge. Included are effects of

shunt loading and residual inductance. Shunt loading is an effect of the ground capacitance shown with dashed lines in Figures 1-1 and 4-1. Loading of the bridge would be compensated by setting the capacitor dial ***high***. Residual L causes effective C to be higher at 1 MHz than at 1 kHz; to compensate, one would set the dial ***low***. Because the former effect predominates, column A is +.

Column B is the 1-kHz correction for mechanical nonlinearities in the particular capacitor you are using. Since GR supplies such data (with the 1422-CLP Precision Capacitor) as terms to be added with the dial reading to obtain true capacitance, copy each number into column B with its sign reversed. If your capacitor is Type 1422-CL (without the correction data) obtain column B by making measurements with a precision, 1-kHz, 3-terminal bridge such as the GR Type 1620-A Capacitance-Measuring Assembly, with an accuracy of 0.01%.

Correction term T is a single number, characteristic of a particular bridge. It may have either sign, + or −. Obtain T from the bottom shield cover of your bridge. If no such term is given, assume T = 0. Paragraph 5.6.8 will correct for any reasonable error in T.

Column C is the true capacitance desired. Obtain column D (the dial setting) by adding A+B+C+T.

NOTE

Although the backlash in the 1422-CL capacitor is less than 1/5 of its smallest scale division, it is good practice to make each setting in the direction of increasing C.

e. Label each of the coaxial capacitance standards with its effective value at 1 MHz, obtained from the calibration certificates supplied with GR Types 1406 and 1407. For Type 1405, use the 1-kHz values (the 1-MHz correction is negligible).

NOTE

For a discussion of standards accuracy, traceability to NBS, and frequency corrections, refer to the editorial "Accuracy Traceability . . . ," ***GR Experimenter***, March/June 1970.

Recalibration. Proceed in the order of Table 5-9, starting with 10.00 pF, finishing with 100.00 pF. Refer to Table 5-8 for the pertinent internal standard to be adjusted at each setting of the bridge. For example:

a. Set the bridge readout to 10.00 pF, and the variable Cx to the corresponding number (column D). Table 5-8 shows, for 2nd digit = 1, the internal standard is A-C1. Adjust it with a screwdriver (Figure 5-3) making SAMPP cross zero at 180° (Figure 5-8). Leave the shield covers on.

b. Similarly, set readout and Cx to 20.00 pF and adjust A-C2, carefully.

c. Because "30.00 pF" uses only the internal standards you have already reset, no adjustment should be necessary. If a minute adjustment is needed, make it mostly in the larger standard involved (A-C2) — set it to most nearly satisfy the criteria of both steps b and c — and recheck steps a, b, c.

Table 5-9

CALIBRATION OF 1422-CL CAPACITOR
(All values: pF)

Corrections general A	Corrections particular B	Capacitance desired C	Set dial to A+B+C+T = D
0.12		10.00	
0.12		20.00	
0.12		30.00	
0.12		40.00	
0.12		40.01	
0.12		40.02	
0.12		40.03	
0.12		40.04	
0.12		40.05	
0.12		40.06	
0.12		40.07	
0.12		40.08	
0.12		40.09	
0.12		40.10	
0.12		40.20	
0.12		40.30	
0.12		40.40	
0.12		40.50	
0.12		40.60	
0.12		40.70	
0.12		40.80	
0.12		40.90	
0.12		41.00	
0.12		42.00	
0.12		43.00	
0.12		44.00	
0.12		45.00	
0.12		46.00	
0.12		47.00	
0.12		48.00	
0.12		49.00	
0.12		50.00	
0.12		60.00	
0.12		70.00	
0.14		80.00	
0.14		90.00	
0.14		100.00	

d. Set readout and Cx to 40.00 pF and adjust A-C4 very carefully. It is involved in the recalibration of all the 3rd, 4th, and 5th-digit standards.

e. Proceed as above, until all 17 internal standards have been checked or readjusted. Notice that A-C17 and A-C18 are permanently connected in parallel; adjust either one.

5.6.8 200-pF-Range Check.

Capacitance. Check the accuracy of the previous adjustments and, if necessary, readjust as follows:

a. Replace the test fixture with Type 1682-P2. Do ***not*** attempt to reset zero at the rear panel. All Type 900 connectors ***must*** be clean and undamaged.

b. Install the 20-pF coaxial C standard on the fixture.

c. Bring the bridge to balance manually, i.e., manipulate the controls to make SAMPP = 0. Record the C and G readouts. Subtract the 1-MHz value of the 20-pF standard from the C readout; call the result "C offset".

d. Similarly, install and manually balance the 10-pF coaxial standard ***without*** moving the test cable. Verify that the C readout equals the 1-MHz value of the coaxial standard plus the "C offset."

e. If not, note the error and verify by repeating steps a-d. Readjust the 10-pF standard A-C1 to make that error zero.

f. Similarly, use the 50-pF coaxial standard for the 40-pF standard A-C4.

g. Similarly use the 80-pF coaxial standard for the second 20-pF standard A-C5.

h. Similarly, use the 100-pF coaxial standard for A-C3,

i. Replace the test fixture with Type 1682-P3, as in para. 5.6.7. Reconnect the variable precision capacitor.

k. Check the critical step at 10, i.e., 9.99 to 10.00, as follows: Set C readout to 9.95; manually balance the bridge; watch the level of SAMPP ***at*** 180° on the scope while manually advancing the C readout 10 counts. (Nominally, each step is 10 mV.) Verify that the critical step is in the range 0 to +2X, where X is the average height of the other steps. Otherwise repeat the recalibration.

l. Similarly, check the critical steps at 20, 30, 40, 50, 60, 70, 80, 90, and 100 pF. The acceptable range for these steps is (at 20) −X to +3X, (at 30) −2X to +4X, and (at each higher checkpoint) −3X to +5X. (Note: We mean by "−3X" a step of 3-times-average height, in the reverse direction.) Recalibrate, if necessary, to meet these requirements. Compromises may be made, for example, adjustment of A-C5 to equalize the critical steps at 80 and 100 pF.

m. If the calibration requirements cannot be met simultaneously, refer to Trouble Analysis, starting perhaps with para. 5.7.9.

NOTE

Coaxial standards may be obtained from General Radio Co. in other useful values (30, 40, 60, 70, 90 pF) on special order.

Conductance. Check conductance accuracy as follows:

a. Install a component mount on the Type 1682-P2 test fixture, with one binding post at the side and a screw at the central position. (Refer to the note in para. 5.2.5.)

b. Manually balance the bridge and record the C and G readouts. The latter is G_o', the G offset on this range.

c. Install the following conductance references, one at a time. Manually balance the bridge and record the bridge readouts for each: 50, 100, 147.1 $\mu\mho$ (20, 10, and 6.8 kΩ, respectively).

d. Verify that the G measurements fall within the check limits for the 200-pF range, as given in para. 5.2.5.

5.6.9 20-pF Range Check.

a. Leave rear-panel switch A-S10 down.

b. Determine the C offset for this range (dependent on your setting of A-C20), as follows. Install a 2-pF coaxial capacitance standard in the test fixture. Manually balance the bridge. If the G readout is greater than 00.07 $\mu\mho$, change the value of A-R33 (in parallel with A-C20, Figure 5-3). Make this readout at least 00.01 $\mu\mho$. Record the G readout as the G offset for this range: G_o. Subtract the 1-MHz value of the 2-pF standard from the C readout and record the remainder as the C offset.

c. Install a 10-pF coaxial standard in place of the previous one. Rebalance the bridge. Verify that the measurement, corrected by subtracting both offsets, is: Value of standard ±.001 pF; G_o + .01 ±.01 $\mu\mho$. If not, the C measurement may be improved by changing the value of K-C36 or K-C37; the G reading by adjusting K-R34 for G_o + .01 $\mu\mho$. (See Figure 5-2.) Recheck the values of the offsets after making such adjustments.

d. Complete the C check by substituting the 5-pF standard and verifying that the measurement is well within the limits tabulated in para. 5.2.4.

e. Complete the G check using the 200, 100, and 68-kΩ references, as before.

5.6.10 2000-pF Range Check.

a. Leave rear-panel switch A-S10 down.

b. Determine the C and G offsets as before: Install a 200-pF coaxial standard; balance manually; subtract the standard value from the C readout. (Do ***not*** attempt to bring the C offset to zero.)

c. Check that the offset $G_o'' < 7$ $\mu\mho$. (There is no pertinent adjustment.)

d. Install a 1000-pF coaxial standard. Balance the bridge. Subtract the C offset from the C readout to obtain the measurement. Subtract the 1-MHz value of the standard from the measurement to get the error.

e. If this C error exceeds 1 pF, reduce it by a change in value of T-C6 or T-C7 (Figure 5-7). If the G readout is not

now within the range: $G_o'' + 1 \pm 1\ \mu\mho$, set it to $G_o'' + 1$ by adjusting T-R9. After such adjustments, repeat steps b, c, d, and e to make sure the compensation is correct.

f. Complete the C check by substituting the 500-pF standard and verifying that the measurement is well within the limits tabulated in para. 5.2.4. For this check, use the C offset found in step b above.

NOTE

If this C offset differs substantially from that measured in para. 5.6.8 for the 200-pF range, A-C23 should be readjusted, but not as part of this recalibration. That is part of the setup for subsequent measurements, with the appropriate test fixture (para. 5.2.3).

g. Complete the G check using the 2000, 1000, and 680-Ω references, as before.

5.6.11 20-nF Range Check.

a. Determine the C and G offsets as before: Install a .002-μF coaxial standard; balance manually; subtract the standard value from the C readout.

b. Check that the offset $G_o''' < 0.7\ m\mho$. (There is no pertinent adjustment.)

c. If the C-offset magnitude is greater than .01 nF, pad or change the value of A-C30 (Beside A-C24, Figure 5-3).

d. Install a 5-nF coaxial standard, balance manually, and calculate the error as before. If the error exceeds 0.1 nF, pad or change the value of T-C10, or T-C16. If the G readout is not now in the range: $G_o''' \pm 0.1\ m\mho$, make the appropriate adjustment in T-R10 (Figure 5-7). If adjustment is made, for either C or G, the offsets may be affected; then, repeat steps a through d.

e. Complete the C check by substituting the 10–nF standard and verifying accuracy as before. Use the C offset found in step a above.

f. Complete the G check using the 200, 100, and 68-Ω references as before.

g. Undo the setup of para. 5.6.2 and return the instrument to normal service.

5.7 TROUBLE ANALYSIS.

5.7.1 General.

Fault isolation to replaceable boards, reed switches, or other small parts is the purpose of the following paragraphs. Pretested replacement boards may be obtained quickly as described in para. 5.1.

Plan. Para. 5.7 is organized for straightforward analysis. Look for the heading that best describes the fault. Under that heading are possible causes, with distinguishing indications. Narrow the possibilities down by comparing these with the known malfunction. (Recheck bridge behavior if there is doubt.) After each cause are helpful suggestions for further troubleshooting. Pursue these by checking signals, measuring voltages, etc., as suggested, until you have identified the cause in sufficient detail.

Guidance. The functional flow diagrams, Figures 6-1 and 6-4 are recommended for understanding normal relationships and analyzing a fault in terms of the signals between boards. The Signal Index, Table 6-1, is a convenient summary of signal descriptions, their causes, effects, and test-point locations. The key to state-indicator lamps is tabulated in para. 5.7.2.

The following paragraphs, particularly the T-board para. 5.7.6, contain further help in detail. Also refer to Section 4 for theory and Section 6 for schematic diagrams, some of which contain voltage and waveform data, and parts lists.

Logic Signals. To monitor and examine logic signals, use a scope. Unlike a logic probe, a scope provides visual indication of pulse width, noise, or an indeterminate state. For example: if 0 to 0.4 V is "0", and +3 to +5 V is "1", then +0.4 to +3 V is an indeterminate state, which means trouble. It usually means the failure of the digital IC that generates the signal, although it could also result from abnormally heavy loading of a circuit in the "1" state.

Reference Designators. The name of each signal indicates its source by its initial letter, except for signals that originate outside the instrument. The bar over a signal name indicates that the primary function is accomplished in the "0" state; the absence of a bar, the "1" state. For example: DIR originates on the D board and directs the I counter in reverse when "1".

Each designator of a test point or anchor terminal (TP or AT) is preceded by the appropriate board letter and hyphen, like designators of component parts (refer to para. 4.1). If one board plugs into another, the mother-board letter comes first, with another hyphen. For example: M-E-107C represents a point on the M board, where the E board connects. Number 107 is a lateral position and C identifies the component side of the E board.

Cables. If the bridge is part of a system, analyze troubles first without any system connections. Remove any cables from the DATA OUTPUT and AUXILIARY connectors. Having checked that the instrument works properly by itself, proceed to analyze any possible faults in the system with the help of the Signal Index and the N and Q schematic diagrams. Such faults may be outside the 1682; they may be in the circuitry, connectors, or cabling of the N and Q boards.

Reed Switches. These relays are prominent in the service section because the reeds have shorter life than most electrical parts, replacement is relatively easy, and many of them are located on boards that are difficult or impossible to replace in the field. Observe the following suggestions:

1. Check each reed switch suspected of being faulty with an ohmmeter having a low source voltage (1.5 V max) and reading about 10 Ω midscale. Be sure to distinguish the terminals of the reed capsule (concentric with the magnet coil) from the coil terminals (on the other side of the etched board).

2. Some reed switches cannot be checked this way in place because they are shunted by dc paths. Open such a path or disconnect one lead of the reed capsule (without bending the leads). Refer to the schematic diagram.

CAUTION

Because the circuit has to be energized to close the contacts being evaluated, beware of misleading or damaging effects of circuit voltage on the meter. Avoid accidental contact of meter leads with various points in the instrument.

3. Check for a resistance of 0 to 0.2 Ω when the switch is closed, infinity (on the ohmmeter scale) when open.

4. Replace a faulty reed switch with the proper one of several types specified in the parts list. Install the new part exactly like the original. The leads are magnetic; their length and locations are significant.

CAUTION

Avoid stressing the leads or bending them near the glass seal. The reed capsule should not press hard against the inside of its hole in the coil assembly. Allow the capsule to "float" freely while the leads are soldered.

Repairs on a Board.

It is recommended that most faulty etched-circuit boards be replaced. (Refer to para. 5.1.) However, the power-supply-regulator board, V, is relatively easy to repair. A well-equipped service facility may repair other boards too.

5.7.2 Failure to Count, Both C and G, Any Mode.

Total power failure; no indicators or readouts. Check the ac power circuits and power supply (para. 5.7.12).

High-voltage power failure; no numerals, but units are lit. Check 250-V power supply and connection to H board.

Counters faulty. It is unlikely that both would fail; they are totally separate. Turn POWER OFF and then on; readout should be random. Press SET ZERO. If readouts do not reset to zero, check I and R boards for dc voltages. Refer also to para. 5.7.3.

Counting-gate flip-flops stay "off"; lamps E-DS6 and E-DS7 (Figure 5-4, Table 5-10) both off. Possible causes: PRIG is "0" (see below). PCLK12 pulses missing (see below), $\overline{\text{ECHANGE}}$ is "0" (can be checked at E-TP21, trouble in range-delay circuit), E-TP6 is "0" (trouble in switching-delay circuit), or E-IC16 $\overline{Q}$ is "0" (indicated usually by E-TP19 being "1", trouble in range-delay circuit). Check dc voltages. Replace E board.

PRIG stays at "0". Possible causes: $\overline{\text{DBAL}}$ is "0" (see below), $\overline{\text{ZSEZR}}$ is "0" (see below), the start-pulse generator is at fault (there should be a 20-ms positive pulse at P-TP7 after each depression of the START button and periodically in the VMR mode, FAST RATE), or the balance flip-flop has failed. Check dc voltages. Check PRIG for short to ground. Replace P board.

Main clock; PCLK12 and PCLK23 both missing in all modes. Check dc voltages. Replace P board. (Be sure RATE is not set to STOP. If the bridge will operate in TESTS 5 mode, use that until replacement is available.)

$\overline{\text{DBAL}}$ stays at "0". Possible causes: $\overline{\text{ZSEZR}}$ is "0" (see below), SAMPP is less than 20 mV pk-pk (see below, ZSENS is abnormal (normal range +7 mV to +5 V dc) or balance recognition circuit is faulty. Check dc voltages. Check $\overline{\text{DBAL}}$ for short to ground. Replace D board.

$\overline{\text{ZSEZR}}$ stays at "0". Possible causes: SET ZERO push button stuck in depressed position, short to ground in front-panel wiring, or faulty Z board. Replace Z board.

SAMPP is less than 20 mV pk-pk; missing or weak error signal. Possible causes: faulty oscillator, ratio-transformer circuitry, or preamplifier. Check TOSCS level (Table 5-12) if zero check OSC and then 0 board, if normal check ratio-transformer circuitry (para. 5.7.6) and service reed switches. Make visual inspection for short to ground. If these are normal and SAMPP is still low on all ranges, replace S board. (Refer also to para. 5.7.8.)

Table 5-10
STATE-INDICATOR LAMPS*

			E board					
	D board Directions		Counting Gates		Auto-Ranging Circuitry			
							Range Selection	
Lamp	DS2	DS1	DS7	DS6	DS1	DS2	DS4	DS3
ON	DIR = "0" C fwd	DRR = "0" G fwd	G open	C open	Step up	Step down	2 or 3	1 or 3
OFF	DIR = "1" C reverse	DRR = "1" G reverse	closed	closed	No command	No command	0 or 1	0 or 2

* Columns arranged to correspond with front view, Figure 5-4.

5.7.3 Failure to Count, C Only, Any Mode.

C counter apparently faulty; readout unchanging or jams at a reading unrelated to measurement, and may not reset to zero. Possible causes: EICLK absent (see below) or faulty I board. Check dc voltages. Replace I board.

Counting gate stays closed, EICLK absent. Possible causes: counter-limit signal stays at "0" (see below) or fault on E board. Check for PCLK12 and PCLK23 pulses, I$\overline{OR}$ and I$\overline{9F}$ both "1", dc voltages. Replace E board.

Counter-limit signal (I$\overline{OR}$ or I$\overline{9F}$) stays at "0". Possible causes: I-board circuit fault, short-circuit to ground. To analyze the latter, remove I and E boards one at a time, rechecking.

5.7.4 Failure to Count, G only, Any Mode.

The trouble analysis is very similar to para. 5.7.3; in reading the signal names containing I, replace I with R.

5.7.5 Failure to Count in Both Directions While Measuring.

C or G readout runs to 19999 or 00000 at first measurement or the first one which requires counting in the "other" direction; in TRACKING mode, bridge will not follow changes in both directions. Possible causes: Cx or Gx too large for the RANGE, DIR or DRR stays at "1" or "0", C-standard reed switch stuck closed (see below), C or G counter faulty. For example, suppose C counter jambs at 19999. Look at DIR-indicating lamp D-DS2, while in the TESTS-5 mode, with the counter set (using TESTS 2) first above, and then below Cx. Refer to Table 5-10. The lamp should be first off, then on. If the counter will not respond to TESTS 2, check for proper signals to the I board. Replace it.

DIR or DRR does not respond to sense of error signal; corresponding lamp stays on in example above. Check for OREF (para. 5.5.1). Look at SAMPP (para. 5.5.3) and run the unknown from one side of balance to the other, as above. If the error signal reverses sense at 180° (Figure 5-8) without DIR being switched (or at 270°, without DRR being switched) try making the adjustments of para. 5.5. If adjustment does not remedy the situation, replace the D board.

DIR or DRR stays at "0" even through corresponding indicator lamp switches on and off. Possible cause: short circuit to ground on M board or corresponding counter. Check for short, with and without pertinent boards installed.

A C-standard reed switch is stuck closed; if C_x is small enough so that reed should be opened for measurement, the counter will go to zero. However, on a lower range it will count up again to full scale, to a proper measurement, or to a "hunting" situation (para. 5.7.7). Analyze using procedures of para. 5.6.3.

5.7.6 T-Board Switching Failures. **Figure 5-7.**

The symptoms are widely varied, depending on which of the 20 reed switches is faulty and depending on whether the fault is failure to open, failure to close, or poor contact when closed. Assume that only one switch is faulty when analyzing a trouble, but after repairing one switch, check carefully for normal performance of the rest.

All these switches are activated by RANGE change. All but 2 (T-K103 and T-K113) are closed only on 1 range (the exceptions are closed on the top 2 ranges). Therefore, symptoms are usually associated with a particular range.

Poor contact; measurements on one range are not repeatable or disagree substantially from measurements of the same capacitor on another range. Check repeatability by switching to another range and then back again. Locate the faulty reed switch as follows: Disconnect B and D portions of the test cable from the test fixture. Keep the instrument POWER on, and select the RANGE that exhibits trouble. Referring to Table 5-11 and Figure 5-7 or 6-37, check that each reed switch that should be closed has contact resistance less than 0.2 Ω. Use an ohmmeter as described in para. 5.7.1 under ***Reed Switches.***

Failure to close; measurements on one range may be repeatable but erroneous, may exhibit loss of sensitivity, or abnormal levels of voltage across Cx. The bridge may even fail to count. Check as in the poor-contact discussion, above.

NOTE

Normal voltage across Cx is 500, 50, 5, and 0.5 mV rms on 20-pF through 20-nF ranges, respectively. Measure with scope probe at CxHI.

Failure to open; measurements on one or more ranges may be affected, exhibiting measurement error, loss of sensitivity or speed, or abnormal levels of voltage across Cx.

Table 5-11

REED SWITCHES CLOSED ON EACH RANGE

Board	Range 20 pF	200 pF	2000 pF	20 nF
F–	K1S	2; 3	2†	—
K–	7	17	—	—
O–	3	2	1	1
S–	—	—	—	1
T–	—	—	—	116
comp	121	—	118	117
hi	109	114	108	110
	112	115	113*	119
lo	100	107	101	105
	104	111	103*	120

*These switches are closed on the top range also.
†Prefix K and suffix S omitted from most of the reference designators for simplicity.

Table 5-12

T-BOARD HI-TRANSFORMER-CIRCUIT CHECKS

(Tabulated in mV pk-pk)

Check point	RANGE				Shorted switch
	20 pF	200 pF	2000 pF	20 nF	
OSC	1560△	310△	155	155	Normal□
(at T–	1000	*	97	*	K110S
TP1	700	250	*	*	K113S
or T–	*	*	58	135	K112S
AT24)	*	250	58	39	K109S
	720	*	*	29	K108S
T-AT44	10	155	0	0	Normal□
(or HI,	150	*	145	155	K114S
A-C24)	1540	*	16	*	K115S
T-AT39	4	0	0	165	Normal□
	158	165	145	165	K119S
TOSCS†	158	158	158	158	Normal□

† at T-AT22 or T-AT15.
* Normal.
△ 155 mV pk-pk if OSC LEVEL is LOW.
□ Tolerance: ±10%.

Check for short-circuited reed switches in 3 groups as follows:

Hi-Transformer Circuits. Set controls to standard settings and scope so channel 1 shows OREF (para. 5.5.1-5.5.2). Install 1682-P3 Test Fixture with no capacitor. Once the scope is set up, switch its preamp mode to channel 2, and use that to measure the signals.

Follow the outline of Table 5-12. At each probe point, measure the signal levels for the 4 principal settings of the RANGE switch. Compare this set of data with normal and abnormal rows in the table (asterisks mean "normal"). If the measured data more nearly matches an abnormal row than the normal one, there is probably a shorted reed switch, indicated in the right column. Replace it.

CAUTION

Avoid stressing the leads or bending them near the glass seal. The reed capsule should not press hard against the inside of its hole in the coil assembly. Allow the capsule to "float" freely while the leads are soldered.

Lo-Transformer Circuits. Follow the same procedure, using Table 5-13 as a guide. However, first modify the test setup as follows (use short clip leads):

1. Test cable "D" connector disconnected.
2. Its *outer* circuit completed by clip lead.
3. Cx = ∞ (Clip lead: CxHI to CxLO).
4. Cs = max (C readout: 19999).

Compensation Circuitry. Follow the same procedure using Table 5-14 as a guide. The setup is unchanged (Cx is still shorted.)

5.7.7 Hunting.

Hunting is indicated by a low measurement rate in the VMR mode (each measurement requires about 2 s, even though RATE is set to FAST). The direction of count reverses endlessly (without recognition of balance) until abortion. Possible causes: a C-standard switch fails, DVCO fails, balance-recognition threshold adjustment is set wrong, OSC level is abnormally high, or $\overline{\text{DBAL}}$ or PRIG stays at "1" for some other reason.

Other possible causes: preamplifier is noisy or has too much gain (S board, para. 5.6.5); phase detectors are out of adjustment (D board, para. 5.5); or the switching-delay circuit is inoperative (E board, para. 4.5.5).

A Cs switch fails to close (hunting results only if the pertinent C standard is required in the measurement – Table 5-8), or fails to open (para. 5.7.5). Explore with the GR 1422-CL variable capacitor, in the TRACKING mode. Replace the faulty reed switch, K board, or L board. Refer also to para. 5.7.9 for hunting that occurs only in the vicinity of a 9-to-0 transition.

Table 5-13

T-BOARD LO-TRANSFORMER-CIRCUIT CHECKS

(Tabulation: mV pk-pk; setup described in text.)

Check point	RANGE				Shorted switch
	20 pF	200 pF	2000 pF	20 nF	
T-AT41	30	41	12	58	Normal□
	4000	*	107	*	K105S †
	144	97	58	*	K120S †
	1600	*	*	*	101 or 111
	1600	160	*	*	K103S
T-AT11	1500	40	58	4	Normal□
	*	1000	*	*	K103S †
	*	1000	20	*	K100S †
	*	165	23	*	K104S †
	*	97	*	*	K101S
	1300	*	30	*	K105S
T-AT33	144	35	20	0	Normal□
	1440	50	*	*	K101S†
	1440	150	*	*	K103S
	1400	*	*	*	K105S
	50	*	*	*	K111S
	*	195	*	*	K100S
T-AT12	30	165	10	0	Normal□
	1500	*	*	*	K111S †
	158	*	58	49	K107S †
	1400	*	*	*	101 or 105
	1000	*	*	*	K103S

* Normal.
† This row is the preferred indication for this switch.
□ Tolerance: ±10%.

Table 5-14

T-BOARD COMPENSATION-CIRCUITRY CHECKS

(Tabulation: mV pk-pk; setup described in text.)

Check point	RANGE				Shorted switch
	20 pF	200 pF	2000 pF	20 nF	
T-AT47	72	60	35	4	Normal□
	1500	160	20	*	K116S
T-AT45	20	0	15	0	Normal□
	1340	155	*	*	K118S
T-AT52	20	0	0	0	Normal□
	250	53	10	*	K117S
T-AT32	1500	0	0	0	Normal□
	*	160	15	*	K121S

* Normal.
□ Tolerance: ±10%.

DVCO fails (or is ineffective); hunting results if balance recognition is prevented by the presence of noise on SAMPP associated with the high counting rate; hunting stops at reduced SENSITIVITY. Check that DVCO is "1" while SET ZERO button is depressed, otherwise "0" (almost immediately) in TRACKING mode. If DVCO remains "1", check SAMPP as in para. 5.6.5; replace D board. If DVCO is normal, check the period of PCLK12 (use channel 1 of scope) in TRACKING mode, while slowly varying Cx. If the period is 2.5 μs, replace the P board; 167 μs is correct.

The balance-recognition threshold may be set wrong. If so, hunting stops at reduced SENSITIVITY. Readjust as in para. 5.5.5.

That adjustment cannot be made and/or $\overline{\text{DBAL}}$ stays at "1" even though the measurement is essentially complete and SAMPP is at null (less than 20 mV pk-pk). Possible cause: D-board failure. Check the D board for dc voltages, monitor SAMPP as in para. 5.5.3. Replace D board. (A possible field repair is to replace D-Q2).

The level of OSC is abnormally high; the capacitor being measured has a higher drive-signal level than is necessary and desirable; hunting, if any, stops when SENSITIVITY is reduced. Probable cause: faulty attenuator on the O board. Compare OSC measurements with the 1st row in Table 5-12. If the level is up around 600 mV pk-pk on the top 2 ranges, O-K2S is probably shorted. If the level of OSC is about 1500 mV pk-pk on all ranges, O-K3S is shorted (fails to open). Replace the O board or the faulty reed switch.

PRIG stays at "1" even though $\overline{\text{DBAL}}$ is "0"; this is very unlikely. Analyze why the balance FF does not flip to the "balance" state; if no cause is found, replace the P board. Also, replace M-CR2.

5.7.8 Low Sensitivity.

With the SENSITIVITY control at MAX, measurements differ depending on whether the bridge counts up or down. Check by switching ranges and using the SET ZERO button. However, to make the bridge count ***down*** on the 20-pF range toward Cx, first momentarily connect another capacitor in parallel with the one in the test fixture. Possible causes: T-board reed switch failure (para. 5.7.6), low level of drive signal OSC, or deficient gain in preamplifier.

Check the bridge drive level by measuring OSC on all ranges; compare data against Table 5-12. If the ratios are correct (10, 2, 1, 1) but the levels low, adjust as in para. 5.6.4; finally, replace the O board. If the level drops to zero on 1 or more ranges, a possible field repair is replacement of a reed switch in the O-board attenuator (Figure 5-4). Reed switches O-K1S, O-K2S, and O-K3S are used on the 2 top ranges, the 200-pF, and the 20-pF range, respectively. Note: if O-K1S is shorted (will not open) the level of OSC will be reduced on the 2 lower ranges, but so little that the bridge will probably function normally in every practical way.

Preamplifier gain is low; SAMPP is below normal level for a known amount of unbalance (para. 5.6.5). Make the adjustment described there; check over the T board (para. 5.7.6); replace the S board. However, if gain is low on the 20-nF range only, and satisfactory on the other ranges, there is a possible field repair. Analyze the circuit controlling the one reed switch on this board. On the 20-nF range, if $\overline{\text{ZRR3}}$ goes to "0" and if S-K1L is energized but contacts S-K1S remain open, replace the reed switch.

5.7.9 Inaccurate or Nonrepeatable Measurements.

General. The bridge performs normally except for accuracy and/or repeatability, measured by the procedures of para. 5.2.4 and 5.2.5. Possible causes: T-board switching failure, bridge in need of recalibration (paragraphs above); F-board compensation, C-standard reed switches making poor contact, associated K-board switches failing to close to ground, or K-board compensation (see below).

F-Board Compensation. This circuitry places a small amount of switched capacitive reactance in series with the test cable D; on the 20-pF range this reactance is zero. The effect of this compensation is a trend that is most noticeable at the high end of each range.

For example, suppose the 200-pF range is being checked as in para. 5.2.4 or 5.6.8. Suppose, for simplicity, the 1-MHz values of the standards are exactly 10, 20, 50, 100 pF. Proceed as follows:

a. Correct the bridge measurements by subtracting the offset C_o, if any. If the trend is up — like this: 10.01, 20.02, 50.06, 100.14 pF — there is too little reactance; F-K1S is shorted or the capacitors in the circuit are too large. If the trend is down — like this: 9.99, 19.98, 49.94, 99.86 pF — there is too much reactance; F-K2S or F-K3S fails to close or the capacitors in the circuit are too small.

b. Check the reed switches on all 4 ranges carefully with an ohmmeter, with the test-cable D connector disconnected. Refer to Table 5-11. Replace faulty switches, or the F board, before changing any of the capacitors.

C-Standard Reed Switches/Poor Contact. If one of these switches (on the K board) makes poor contact, symptoms are nonrepeatable and generally high indications of G. Make a thorough check as follows:

a. Use the precision variable capacitor for Cx (para. 5.5.1); set the mode to TRACKING; otherwise use standard settings.

b. Referring to Table 5-8 for the corresponding readouts, adjust Cx so as to switch A-C1 in and out several times. Verify that the G readout is low and repeatable.

c. Repeat this procedure for A-C2, A-C4, A-C5, and A-C3.

d. If indication of poor contact is found in any instance, replace the K board or the reed switch involved (K-K1S, K-K2S . . . K-K5S).

Table 5-15

K-BOARD SWITCHING AT KEY TRANSITIONS

To make Cs increase to	This signal goes to "0"	This switch closes	Connecting this std C	This ground switch opens	This compensator opens
10 pF	I$\overline{Q}$4	K1S*	A-C1	K12S*	K10S*
20	I$\overline{Q}$3	K2S	A-C2	K13S	K9S
40	I$\overline{Q}$2	K3S	A-C4	K14S	K8S
80	I$\overline{Q}$1	K4S	A-C5	K15S	K11S
100	I$\overline{Q}$0†	K5S	A-C3	K16S	K6S

* Prefix K— understood.
† When I$\overline{Q}$0 goes to "0", the other 4 signals go to "1".

K-Board Shunt Compensation and Grounding Switches. These switches open when the corresponding C standard is part of Cs and close when it is not. They are essential to smooth transitions as each of the 5 main standard capacitors is switched in or out. Depending on the sense of the error, if such a transition is not smooth, it will contain a small range of measurements in which hunting can occur or the sensitivity is apparently reduced. If one of the grounding switches does not close properly (they all should when the SET ZERO button is pressed) the offset C_o or the zero adjustments may be noticeably abnormal. If one of the compensation switches does not, shunt-loading abnormality will affect the ratio transformers. To make a thorough check, proceed as follows:

a. Remove the D board and control the counters manually, watching SAMPP with a scope and varying Cx at will (para. 5.6.2 and 5.5.3).

b. Balance the bridge at a readout of 9.999 pF. Set RATE to about 1 count per s and flip the C direction forward and reverse, as required to traverse several counts above and below the "10-pF" critical step, several times.

c. Verify that SAMPP makes a jump of the same magnitude at this critical step as at the other nearby steps. The tolerance is given in para. 5.6.8.

d. Repeat that procedure at 20, 40, 80, and 100 pF.

e. If an irregular transition occurs (step c is not verified) at any of these transitions, probable cause is failure of a K-board switch (unless a C standard is out of adjustment). Refer to Table 5-15. If a fault occurs at 10, 20, 40, or 80 pF, another fault will also occur at 100 pF, *not* related to I$\overline{Q}$0. However if a fault of this kind occurs only at 100 pF, it is related to I$\overline{Q}$0. Replace the K board or verify the identity of the faulty switch, using an ohmmeter, and replace the part.

K-Board Range Compensation. This compensation for effects of test-cable parameters on the ratio transformers is switched in for the 200-pF and 20-pF ranges only. The fault appears in normal measurements as inaccuracy on one of these ranges. In the calibration procedure, trouble is indicated as follows: the ratio-transformer check on the 200-pF range (para. 5.6.6) or the range-accuracy check on the 20-pF range (para. 5.6.9) is invalid. The capacitor changes or adjustments recommended there are ineffective.

Probable cause: a faulty switch. Verify that Z$\overline{RR1}$ drives the switch coil K-17L on the 200-pF range, Z$\overline{RRO}$ drives K-K7L on the 20-pF range. Check the corresponding reed switch with an ohmmeter. Replace the faulty switch or the K board.

5.7.10 Auto-Ranging Capability. **Figure 6-4.**

General. Refer to para. 4.4, particularly to the timing diagrams, for an understanding of the circuit functions. Figure 6-4 shows the main signal paths and Table 5-10 gives the indicator-lamp code.

Use of the TESTS modes, so that the counting and auto-ranging process can be slowed down and stopped at will, may be a powerful diagnostic tool. Because each delay (T1, T2) is only 6 ms, "up" or "down" indicator E-DS1 or E-DS2 can be seen only if the main clock is very slow (or there is a peculiar circuit failure).

Another diagnostic tool is the provision for setting the auto-range circuitry to the 20-nF range, with E-DS3 and E-DS4 lit and Z$\overline{RNG3}$ at "0". Touch pin M-E-115E to ground.

We assume below that the bridge functions normally when the RANGE switch is set for one range, abnormally for AUTO.

Range-Change Circuit Fault. Up or down-range conditions are met (E-DS1 or E-DS2 is lit, TP20 is at "0" state) but range does not change, i.e., the Z$\overline{RNG}$-series signal pattern remains unchanged. (Whether E-DS3 or E-DS4 changes is not a sufficient criterion.)

Check that PCLK12 and PCLK23 are present at M-E-71C and M-E-107C, respectively; check for dc voltages. Replace the E board.

Range-Change Command Is Missing. Up-range command does not appear when a counter has reached its upper limit and is still directed forward, or down-range command does not appear when it should; TP20 stays at "1"; E-DS1 and E-DS2 remain off.

Check carefully for presence of the appropriate signals — up-ranging: I9F, R9F, and ZERNG; down-ranging: I00, R00, and ZERNG — and dc voltages. Replace the E board.

Duplication. More than one of the ZRNG-series signals is "0" at once. Although a measurement may apparently go to completion, the readout will be meaningless. In some cases the C readout will show more than one decimal point.

Check the states of these signals at the M board, M-Z-40C, M-Z-42C, M-Z-43C and M-Z-44C for ZRNGO through ZRNG3, respectively. Unplug the E board to determine whether it is responsible for the duplication. If so, replace the E board. However, if any of the ZRNG-series signals is "0" with the RANGE switch at AUTO and the E board out, the fault is elsewhere, probably in the front-panel wiring or Z board.

5.7.11 Various Special Functions.

This paragraph contains notes and suggestions for trouble analysis related to special functions. The functional block diagrams (Figures 6-1, 6-4) as well as the Signal Index (Table 6-1) the schematic diagrams, and Theory Section 4 are most useful troubleshooting aids.

Start. Look for a "0" of 75-ms duration at P-TP9 after each depression of the START button. Check that ZSTART is normally "1". Look for a "1" of 20-ms duration at P-TP7, either resulting from a manual start signal or repeating periodically when the mode is VMR and the RATE is reasonably slow. Check that NINH is not grounded.

Zero-setting. If the SET ZERO button returns the counters to zero only momentarily, but does not hold them there while the button is still depressed, the fault is in ZSEZR.

Bias. If bias measured at the EXT METER jack with a high-impedance meter is zero regardless of the source (10 V, 100 V, or REMOTE) check as follows:

a. Remove any plug from the START jack.

b. Set the RANGE switch to one of the 4 ranges.

c. If bias is still ineffectual, switch BIAS OFF.

d. Check with an ohmmeter, from ground to T-AT9 or T-AT27, T-AT7, and T-AT40 (Figure 5-7). The lowest reading (under 100 kΩ) indicates the faulty circuit as follows: T-AT9, Test cable E or test fixture; T-AT7, reed switch Z-K1S or associated circuitry; T-AT40, cable to EXT METER jack A-J15.

Speed of Balance. If the measurements take longer than they should according to the discussion in para. 3.11, check that DVCO switches to "1" as the bridge counts more than about 70 increments (least-significant C-digits) from balance in the TESTS 1 mode.

Table 5-16

POWER-SUPPLY CHECKS

Test point †	Unregulated voltage, dc*	Ripple pk-pk, typical	Nominal dc current △
A-C50	+21.5 V	0.97 V	1.3 A
A-C51	−21.5	0.6	0.55
A-C52,−	−5	0.83	1.6 A
A-C52,+	+5.0	0	——
A-C53, A	+250	0.9	0.044

† See Figure 5-2.
* Reference: chassis ground.
△Without Option 2 or 5.

Other Functions. Refer to the functional block diagrams, schematic diagrams, and theory discussions. Check signal behavior and continuity from board to board. Check for a short circuit to ground if a signal stays at "0". If the fault can be isolated to a replaceable board, the quickest repair is usually board replacement.

5.7.12 Power Supply. Figure 6-40.

Bear in mind the inter-dependencies of the power supply regulators when servicing them. Refer to para. 4.7 for theory of operation. The −15-V regulator is pivotal; the +15-V regulator is its dependent twin. The +5-V regulator depends on both of them. The +10-V regulator (although it has its own voltage adjustment) depends on all the others.

NOTE

Ripple on each regulated output (A-J6, pins 10, 20, 27, 30) should be < 10 mV pk-pk.

Loss of Primary Power. No indicators or readouts are illuminated; no reed switches can be heard; no voltage is measured at EXT METER when BIAS controls are both cw.

Check the fuse, with an ohmmeter. Replace it if necessary, and check that the line-voltage switch is set correctly before turning POWER on again.

Disconnect power line and check continuity, with an ohmmeter, through POWER switch, fuse, A-CB1, etc. If no fault can be found, refer below to "Abnormally High +5-V Potential".

Loss of −15-V potential. Although the numerical readouts are lit, all other indicators stay off; "nothing works".

Check dc voltages as described in para. 5.5.1; all depend on the −15-V bus. Check unregulated voltage at A-C51, ripple, and current compared with the typical values in Table 5-16. The IR drop across R9 is a good indicator of current. Use a scope to look at ripple; if it is 50% or more above normal, notice the frequency.

If this current is more than 20% high, look for short circuits or other abnormal load conditions; check V-C5; isolate parts of the load by removing some etched boards and disconnecting the −15-V wire to others.

If this current is zero and the unregulated voltages are normal, check for continuity through the series-regulator transistor A-Q51. Check for open connections; check the transistor.

If the ripple voltage is high, possible causes are: abnormally high current, a faulty filter capacitor A-C51, or (particularly if the ripple frequency is 60 Hz instead of the normal 120 Hz) a faulty diode A-CR52 or A-CR53.

Abnormally High +5-V Potential. Symptoms are similar to ***loss of primary power.*** Protective device A-CB1 acts very quickly, but resets after a brief cooling period.

With a scope, monitor the primary voltage across A-T1, terminals 1 to 4. Look for momentary appearances of line voltage with relatively long periods of zero. With a Variac® adjustable autotransformer, e.g., GR W5MT3A, reduce the line voltage enough to allow A-CB1 to stay on.

Verify that the +5-V regulator is working properly, i.e., that its bus stays at about 1/3 of the absolute level of the −15-V bus. If that fraction is much above 1/3, check over the +5-V regulator. Otherwise check over the −15-V regulator.

Loss of +15-V potential. A maze of superimposed numerical readouts appears but no other indicators (no units of measurement). Both +5-V and +10-V busses are affected.

Check this regulator by a procedure similar to the suggestions for the −15-V regulator.

Loss of +10-V potential. A maze of superimposed numerical readouts appears with units of measurement but no other indicators. No other regulated dc busses are affected.

Check this regulator point-by-point on the V board and replace any faulty part.

Loss of +5-V potential. A maze of superimposed numerical readouts appears, without other indicators (as in +15-V failure). The +10-V dc bus is affected, but not the +15-V. Check the circuit as recommended above.

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NOTE

Each reference designator used in our schematic diagrams and circuit descriptions now includes an initial letter, before a hyphen, to identify the subassembly. The numeric portion of each designator is generally shorter than would be the case if a block of numbers were assigned to each subassembly. The letter before the hyphen may be omitted only if clearly understood, as within a subassembly schematic diagram.

Examples: B-R8 = B board, resistor 8; D-AT2 = D board, wire-tie point 2; CR6 on the V schematic is a shortened form of V-CR6 = V board, diode 6. The instrument may contain A-R1, B-R1, C-R1, and D-R1.

Parts lists and etched-board drawings appear just before corresponding reference views or schematic diagrams.

ELECTRICAL PARTS LIST

MAIN FRAME (A- PREFIX)

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
CAPACITORS*					
C6 thru C9	Adjustable Standard	1615-2110	24655	1615-2110	
C10 thru C13	Adjustable Standard	1615-2120	24655	1615-2120	
C14 thru C18	Adjustable Standard	1615-2200	24655	1615-2200	
C19	Plastic, 0.22 µF	4860-7951	84411	663UW, .22 µF 5%	
C20		1615-2120	24655	1615-2120	
C21,C22	Plastic, 0.22 µF	4860-7951	84411	663UW, .22 µF 5%	
C23	Trimmer cap. asm.	1615-2200	24655	1615-2200	
C24 and C25,C30	Mica., 27 pF ±5%	4700-0235	88419	CM22D, 27 pF 5%	5910-974-5716
C31	Ceramic, 1.8 pF ±5%	4400-0180	78488	GA, 1.8 pF 5%	
C32	Mica, 16 pF ±5%	4700-0210	14655	22ASQ16JC	
C50	Electrolytic, 3400 µF	4450-6221	56289	32D342G030BAGB	
C51	Electrolytic, 1860 µF	4450-5610	37842	20-0000224700102	
C52	Electrolytic	4450-6222	80183	32D722G0115BA6B	
C53	Electrolytic, 100 µF	4450-0800	56289	D28936	5910-970-1589
CIRCUIT BREAKER					
CB1	Voltage-sensitive, 6.2 V	1926-2000	24655	1926-2000	
CONNECTORS					
J1	Multiple Socket	4230-2715	95354	91-6015-1201-00	5935-688-9924
J2 thru J5	Multiple Socket	4230-2710	95354	91-6010-1201-00	5935-688-9923
J6	Multiple Socket	4230-4600	05574	2VH30/1JN-5	
J7	Signal Jack	4260-1050	82389	112B	
J8	BNC Jack	4230-2301	09408	UG-1094A/U	
J9	Multiple Socket	4230-5115	95354	90-110-13	
J15	BNC Jack	4230-2301	09408	UG-1094A/U	
J50 thru J52	Multiple Socket	4230-0129	22526	20049	
J53	Multiple Socket	4230-0129	22526	20049	
J55	Power Plug	4240-0600	24655	4240-0600	5935-816-0254
DIODES					
CR50 thru CR57	Type 1N4140	6081-1014	13327	1N4140	
CR58 thru CR61	Type 1N3254	6081-1002	09213	1N3254	5961-082-3988
INDICATORS					
V1 thru V9	Numerical display tubes	5437-0845	83781	NL-845	
FUSES					
F50	Fast-acting, 1.25 A	5330-3550	71400	AGC, 1-1/4 Amp.	
F51	Slo-blo, 0.6 A	5330-1100	71400	MDL, 6/10 Amp.	5920-976-1586
RELAY					
K1		6090-1100	71482	PRA-2013E	
RESISTORS					
R1; S7	Pot. Comp., 1 MΩ with switch	6045-5100	01121	JS, 1 MΩ 10%	
R2	Pot. Comp., 100 kΩ ±10%, 10 kΩ	6045-2000	01121	JT, 2 MΩ 20%	
R3	Pot. Comp., 10 kΩ	6000-0600	01121	JU, 10 kΩ 10%	
R32Δ	Comp., 5.1 MΩ ±5%	6100-5515	01121	EB, 5.1 MΩ 5%	
R33Δ	Comp., 30 MΩ ±5%	6100-6305	01121	EB, 30 MΩ 5%	
R50	Wire Wound, 1 Ω ±10%	6760-9109	75042	BWH, 1 Ω 10%	
R51	Comp., 100 Ω, ±5%	6100-1105	01121	RC20GF101J	5905-190-8889
R52	Comp., 220 Ω ±5%	6110-1225	01121	RC32GF221J	5905-279-2053
R53	Comp., 270 kΩ ±5%	6100-4275	01121	RC20GF274J	5905-190-8865
SWITCHES					
S1	Rotary Wafer	7890-5308	24655	7890-5308	
S2	Rotary Wafer	7890-5307	24655	7890-5307	
S3	Rotary Wafer	7890-5306	24655	7890-5306	
S4	Rotary Wafer	7890-5309	24655	7890-5309	
S5 and S6	Pushbutton	7870-1511	81073	4001 N.O.	
S8	Toggle	7910-0790	95146	MST-105D	
S10	Slide	7910-0771	76854	277	
S50	Toggle	7910-1300	04009	83053-SA	5930-909-3510
S51	Slide	7910-0831	42190	4603	
TRANSFORMER					
T1	Power transformer	0365-4060	24655	0365-4060	
TRANSISTORS					
Q50	Type 2N3740	8210-1121	93916	2N3740	
Q51	Type 40250	8210-1095	12672	40250	
Q52	Type 2N3055	8210-1097	12672	2N3055	

*C1 thru C5 Standard Capacitors are replaceable only by the factory.
ΔTypical part. Final value is selected by Calibration Lab.

Table 6-1
SIGNAL INDEX (1682)

Interface Signals*		Interior Signals†	Description	Block Diag.	Principal addresses△
ABIAS	β		Bias voltage, analog, from external source. Effective only if BIAS switch at REMOTE.	6-4	A-J8; M-Z-45C; T-AT7.
ABORT	α		"1" indicates measurement has been aborted. ABORT is external, inverted form of PABORT.	–	Q-42E.
ARNG	α		"0" selects automatic ranging, "1" enables RNG-series; if range switch set to REMOTE (cf. QARNG).	–	Q-26E.
BAL	α		"0" indicates measurement completed (balance or abortion). BAL is ext, inverted form of PDBAL.	–	Q-18C.
CLEAR	α		"0" (external) resets a flipflop on Q board, making NEWDATA = "0".	–	Q-20C.
CLK12	α		Ext, inverted form of PCLK12 (the main clock). Count advances at "1" transition.	–	Q-15C.
		DBAL	"0" when balance recognized (|SAMPP|–ZSENS < 1 count), -or while ZSEZR is "0". This makes PRIG also "0". DBAL = "0" changes balance FF to bal at conclusion of normal measurement (PABORT, EDWN, and ECHANGE each "1"; P-TP7 = "0").	6-1	M-D-113E; M-P-40E.
		DIR	"1" when $C_x < C_s$; "1" directs I counter to reverse.	6-1	M-D-114C.
		DRR	"1" when $G_x < G_s$; "1" directs R counter to reverse.	6-1	M-D-112C.
		DUNBAL	"1" when |SAMPP|–ZSENS > 18 counts, turns on UNBALANCE indicator light.	6-4	M-D-112E.
		DVCO	"1" when |SAMPP|–ZSENS > 70 counts, switches counting-rate oscillator to higher of 2 rates and enables RANGE indicator. "0" for smaller error and during 6-ms reed-switch delay (at every change in IQ4).	6-4	M-D-111E; M-P-53E.
		ECHANGE	"0" during T2 (6 ms) of auto-range sequence, inhibits counting (holds EICLK = ERCLK = "0"). Also holds (but will not set) balance FF at unbal (PBUSY = "1").	6-4	M-E-109E; M-P-33C.
		EDWN	"0" while bridge is auto-ranging down; holds (will not set) balance FF at unbal (PBUSY = 1); turns on E-DS2. Note: An unnamed signal at E-TP2 is "0" during autorange up, lighting E-DS1; no effect on PBUSY.	6-4	M-E-106E; M-P-33E.
		EICLK	I-counter clock pulse (C side) is "1" for 400 ns, sync with PCLK23 unless inhibited. Note: inhibited by counter reaching limit, reed-switch delay, auto-range delay, certain TEST modes, or PRIG = "0".	6 1	M-E-83E; M-I-51E.
		ERAN	"1" when either counter at a limit; lights RANGE indicator if DVCO also "1", showing bridge cannot balance on present range.	6-4	M-E-72E; M-Z-98C.
		ERCLK	R-counter clock pulse (G side) is "1" for 400 ns, sync with PCLK23, unless inhibited (cf. EICLK).	6-1	M-E-84C; M-R;110E.
		I9F	"0" when I count is 19999 (IQ-series at upper limit) and DIR = "0"; holds EICLK = "0".	6-1	M-I-12C; M-E-97C.
INHIBIT	δ		"1" = true | If either true, NINH = "0", inhibiting automatic start in VMR mode	–	Q-45E
INHIBIT	α		"0" = true | or count in any TEST mode, also disabling SING1 and START/S (not ZSTART).	–	Q-SO1, pin 45
		100	"1" when I count is 00XXX, a requirement for auto-ranging down.	6-4	M-I-31E; M-E-108E.
		IOR	"0" when I count is 00000 (IQ-series at lower limit) and DIR = "1"; holds EICLK = "0".	6-1	M-I-31C; M-E-82E.
		IQ-series	IQ0 . . . IQ16. Q outputs of I counter. This series controls numerical C display. IQ0 = "1" makes most significant (spill) digit = 1.	6-1	M-I-13 . . . M-I-29.

Table 6-1 (Cont)
SIGNAL INDEX (1682)

Interface Signals*		Interior Signals †	Description	Block Diag.	Principal addresses△
		IQ-series	IQ . . . IQ16. Complement of IQ-series, switches C stds and K-board compens, provides output data.	6-1	M-I-34 . . . M-I-50.
		IQ4	Initiates 6-ms delay whenever reed switches change C standards.	6-1	M-E-71E
IR	α		"0" indicates $C_x < C_s$ (I counter reversed); external, inverted form of DIR.	–	Q-13C
		LOBU	C_sLO, the bridge point where standard arm connects to "low" ratio transformer.	6-1	T-AT10; F-AT1
		LOBUI	Low terminal of G standard, connected to LOBU by dc-blocking capacitors.	6-1	J-AT6; J-AT7; A-J4, 4.
NEWDATA	α		If CLEAR was pulsed, NEWDATA = "0". When measurement completed (balance FF goes to bal) and after 100 μs delay (PBUSY goes to "0") NEWDATA switches to "1", indicating "new data ready".	–	Q-21C
		NINH	"0" inhibits start of new measurement by disabling start-pulse generator. "0" also disables SING1 and START/S by making NSING2 and QSING1 each "1". TEST functions are not inhibited.	–	N-B25; M-P-20.
		NSING2	Internal response to START/S (if NINH = "1"). "0" transition is start command must be held 20 μs min, may be held indefinitely; but "1" duration = 75 ms min to enable subsequent start by NSING2 or ZSTART (cf. QSING1).	–	N-B26; M-P-22C
		OREF	Phase reference signal from bridge oscillator to D board; freq = 1 MHz.	6-1	T-O-28; M-D-77.
		OSC	Main output signal from bridge oscillator to T board; freq = 1 MHz.	6-1	T-O-25; T-TP1
OSCL	α		"0" makes QOSCL = "1", if ZROSC = "0"; i.e., selects low if OSC LEVEL switch at REMOTE.	–	Q-47E
		PABORT	Set to "1" by start command, held "1" in TRACKING or TEST modes. In other modes, if bridge unbal (PBUSY = "1") for 2s, PABORT goes to "0". That makes PDBAL = "1", balance FF go to bal (unless auto range in process) and PBUSY = PRIG = "0", stopping counters & counting-rate OSC until next start.	–	M-P-19C
		PBUSY	"1" in unbal state of balance FF, "0" in bal state (stops count in 2 modes; cf. PRIG), except PBUSY transitions are delayed 100 μs. PBUSY set to "1" and held 20 ms by start command, goes to "0" after PDBAL = "1", unless EDWN or ECHANGE = "0". "0" transition indicates measurement completion, if mode s SINGLE MEAS or VMR.	–	M-P-21C
		PDBAL	"1" if balance or abortion (DBAL or PABORT = "0"); "0" maintains (will not set) PBUSY = "1".	–	M-P-40C
		PCLK12	Bridge clock signal, rectangular wave. Freq = 0.4 MHz, 6 kHz, (from counting-rate OSC) or in TEST modes 1-1000 Hz (cf. PVMR). Generates PCLK23; synchronizes counting-gate logic and auto-ranging.	6-1	M-P-53C or -21E; M-E-71C.
		PCLK12	Inverse of PCLK12. Used in D board to synchronize updating of DIR and DRR.	6-1	M-P-52C; M-D-113C.
		PCLK23	Bridge clock pulse; "1" duration = 400 ns. Rise coincides with fall of PCLK12. All counting is synchronized with PCLK23.	6-1	M-P-43C; M-E-107C.
		PRIG	"1" in unbal state of balance FF (cf. PBUSY) or when mode is TRACKING or TESTS ("0" if none of these); except PRIG = "0" if STOP or DBAL or ZSEZR = "0" or mode or RANGE switch between detents. "1" needed for counting; "0" closes counting gates and stops counting-rate oscillator.	6-1	M-P-22E; M-E;84E.
PRINT	δ		"0" transition = print command, generated by "0" transition of PBUSY or PABORT.	–	N-S01, 24; N-AT26 or -29.

Table 6-1 (Cont)
SIGNAL INDEX (1682)

Interface Signals*		Interior Signals†	Description	Block Diag.	Principal addresses△
		PVMF	Output of variable-meas-rate generator; freq = 1-1000 Hz. "1" transition = start command in VMR mode. "0" duration varied by RATE control, is extended indefinitely by RATE switch set to STOP, or (in VMR or SING MEAS modes) by unbal state of balance FF. PCKL12 = PVMR in any TEST mode.	–	M-P-30C.
		QARNG	Internal, inverted form of ARNG. "1" enables auto-ranging if RANGE switch at REMOTE.		Q-30C; M-Z-38C.
		QOSCL	"1" sets oscillator level low, "0" normal. These states set by OSC LEVEL switch when LOW or NORMAL. But if REMOTE, ZROSC = "0" and QOSCL is internal, inverted form of OSCL.	–	Q-15C; M-Z-99C.
		QSENS	Internal, filtered form of SENS (remote, analog sensitivity setting).	–	Q-5C; M-Z-101C.
		QSETO	Internal, buffered form of SETO. "0" sets counters (hence, standards and data readouts) to zero.	–	Q-17C; M-Z-20E.
		QSING1	Internal, buffered from of SING1, if NINH = "1" QSING1 "0" transition is a start command; rep rate = 50 Hz max; duration of "0" = 2 μs to 20 ms. Note: if NINH = 1, any start command (including NSING2 and ZSTART) resets balance FF to unbal (cf. PBUSY; PRIG) and returns PABORT to "1".	–	Q-19C; M-P-19E.
		R9F	"0" when R count is 1999 (RQ - series at upper limit) and DRR = "0"; holds ERCLK = "0".	6-1	M-R-75C; M-E-97E.
RAN	α		External, inverted form of ERAN. RAN = "0" indicates RANGE light is on.	—	Q-43E
		R00	"1" when R count is 00XX, a requirement for auto-ranging down.	6-4	M-R-90E; M-E-107E.
RNG-series	α		RNG0 . . . RNG3. If RANGE switch at REMOTE and ARNG = "1", range selection; only one signal of RNG-series may be "0"; ZRNG-series is slaved (cf. ZRNG).	–	Q-27E, -7C, -1C, and -2C, respectively.
		ROR	"0" when R count is 0000 (RQ-series at lower limit) and DRR = "1"; holds ERCLK = "0".	6-1	M-R-90C; M-E-85C.
		RQ-series	RQ0 . . . RQ12. Q outputs of R counter, controls numerical G display. RQ0 = "1" makes most significant (spill) digit = "1".	6-1	M-R-76 . . . M-R-88.
		RQ-series	RQ0 . . . RQ12. Complement of RQ-series, switches G standards and provides output data.	6-1	M-R-97 . . . M-R-109.
RR	α		"0" indicates $G_x < G_s$ (R counter reversed); external, inverted form of DRR.	–	Q-14C.
		SAMPP	Amplified error signal (after S-board preamp). Frequency = 1 MHz.	6-1	S-AT2; S-AT10; M-D-90.
SENS	α		Analog external sensitivity control; internal, filtered form is QSENS. Determines ZSENS (balance reference) if SENSITIVITY switch at REMOTE. Max/min sens control limits = +7 mV/+5 V.	–	Q-44E
SETO	α		"0" sets counters to zero, but does not inhibit counting. Int buffered form is QSETO.	–	Q-38E
SING	α		External, buffered control of ZSING, if ZRMOD = "0" (i.e., mode switch at REMOTE). Note: SING is superfluous; TRACK and VAR determine mode. (Refer to truth table at right.)	–	Q-28E
SING1	α		"0" transition is start command. Rep rate = 50 Hz max; "0" duration = 2 μs to 20 ms. Internal, buffered form is QSING1. Inhibited if NINH = "0". Refer to QSING1.	–	Q-39E
SHIFT	δ		"1" indicates abortion. Used to shift color of printout. External, inverted form of PABORT.	–	N-S01, 48; N-AT27 or -28.

SING	0	1	0	1	0	1
TRACK	1	1	0	0	1	1
VAR	1	1	1	1	0	0
mode	Sing Meas		Tracking		Var Meas Rate	

Table 6-1 (Cont)
SIGNAL INDEX (1682)

Interface Signals*		Interior Signals†	Description	Block Diag.	Principal addresses△
START/S	δ		A start command, if not inhibited by NINH. N board may be wired for desired triggering characteristics. Internal, buffered response is NSING2. Refer to NSING2 and QSING1 for limitations.	–	N-S01, 49; N-AT1.
STOP	α		"0" arrests counters by holding PRIG = "0" The 2-s period to abortion is not extended.	–	Q-11C
		T-AT30	Master ground, at tap on "hi" ratio transformer.	6-1	T-AT30
		TDET	Error signal at tap on "low" ratio transformer. Input to preamp, S board. Frequency = 1 MHz.	6-1	T-AT35
		TOSCS	C_sHI, bridge point common to 1 MHz excitation, "high" ratio transformer, and standard arm.	6-1	T-AT15, -21, -22, -43; K-AT21; L-AT1; J-AT3.
TRACK	α		"0" selects tracking mode, if ZRMOD = "0", by making ZTRACK = "0". Refer to SING.	–	Q-29E
UNBAL	α		External, inverted form of DUNBAL. "0" indicates UNBALANCE light is on (error—ref > 18 counts).	–	Q-16C
VAR	α		"0" selects var-meas-rate mode, if ZRMOD = "0", by making ZVAR = "0". Refer to SING.	–	Q-31E
VMR	α		External, inverted form of VMR-generator output PVMR.	–	Q-17C
		ZBIAS	Bias voltage (int or ext) analog, positive; automatically removed by RANGE switch at AUTO.	6-4	M-Z-77C
		ZBLK	"0" when OSC LEVEL switch at LOW, blanks C 5th digit on all ranges, and G 4th digit, all except 2000-pF range. (Data output not affected.)	6-1	Z-H-64E
		ZERNG	"1" if RANGE switch at AUTO, or REMOTE and QARNG = "1" "1" enables autoranging (E board).	6-4	M-Z-43E; M-E-108C
		ZOSC	Inverted form of QOSCL. ZOSC = "1" when OSC LEVEL switch at NORMAL, or REMOTE (ZROSC = "0") and OSCL = "1". This sets OSC level normal. Otherwise ZOSC = "0"; making OSC level low.	6-1	M-Z-78E
		ZPCON	"0" when any phone plug in EXT START jack. Enables bias safety circuit.	6-4	A-J7, 1
		ZQRNG	"0" enables remote selection of range. ZQRNG = QARNG (inverse of ARNG) if RANGE switch at REMOTE; otherwise ZQRNG = "1", which inhibits all RNG-series control.	–	M-Z-39C
		ZRMOD	"0" only when mode switch at REMOTE, enables remote selection of mode. Refer to SING.	–	M-Z-24E
		ZRNG-series	Range determination, single "0" selected by RANGE switch, auto-range circuits, and RNG-series. Refer to truth table. Each ZRNGX is duplicated by corresponding ZRRX. ZRNG-series controls decimal-point and unit indicators, affects auto-range logic, and generates output data.	6-4	M-Z-40C, -42C, -43C, -44C, respectively; M-E-116C, -115C, -113C, -114C, respectively.
		ZRR-series	Reed-switch driving signals, slaved to ZRNG-series. Used to set transformer ratios, attenuation of bridge-oscillator signal OSC (depends also on ZOSC) and compensation on F, K, S, T boards.	6-4	M-Z-37E or -38E, -39E, -40E, -41E; T-AT2, -3, -4, -5, respectively.
		ZROSC	"0" when OSC LEVEL switch at REMOTE; enables OSCL.	–	M-Z-100C
		ZSENS	Analog voltage reference for D-board comparators. Set by SENSITIVITY control in range 7 mV to 5 V (MAX to MIN) except when assoc switch at REMOTE. Then ZSENS is QSENS with additional filtering. Nearly linear range corresponds to 1-50 counts of I (C) counter.	6-1	M-Z-99E; M-D-109E.

ZRNG0	ZRNG1	ZRNG2	ZRNG3	Range	E-DS3	E-DS4
0	1	1	1	20 pF	off	off
1	0	1	1	200	on	off
1	1	0	1	2000	off	on
1	1	1	0	20 nF	on	on

This table is continued on page 6-6.

FEDERAL MANUFACTURER'S CODE

From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1
(Name to Code) and H4-2 (Code to Name) as supplemented through August, 1968.

Code	Manufacturer
[illegible]	Jones Mfg. Co, Chicago, Illinois
[illegible]	Kaiser Electronics Corp, L. A., Calif
[illegible]	Schweber Electronics, Westburg, L.I., N.Y.
[illegible]	Aerovox Corp, New Bedford, Mass
[illegible]	Alden Products Co, Brockton, Mass
[illegible]	Allen-Bradley Co, Milwaukee, Wisc
[illegible]	Leeds Radio Company, N.Y.
[illegible]	Litton Industries Inc, Beverly Hills, Calif
[illegible]	Texas Instruments, Inc, Dallas, Texas
[illegible]	Ferroxcube Corp, Saugerties, N.Y. 12477
[illegible]	Fenwal Lab Inc, Morton Grove, Ill
[illegible]	Amphenol Electron Corp, Broadview, Ill
[illegible]	Fastex, Des Plaines, Ill 60016
[illegible]	Carter Ink Co., Camb Mass 02142
[illegible]	G E Semicon Prod, Syracuse, N.Y. 13201
[illegible]	Grayburne, Yonkers, N.Y. 10701
[illegible]	Pyrofilm Resistor Co, Cedar Knolls, N.J
[illegible]	Clairex Corp, New York, N.Y. 10001
[illegible]	Arrow-Hart & Hegeman, Hartf., Conn. 06106
[illegible]	Digitronics Corp., Albertson, N.Y. 11507
[illegible]	Motorola, Phoenix, Ariz 85008
[illegible]	Engr'd Electronics, Santa Ana, Calif 92702
[illegible]	Barber-Colman Co, Rockford, Ill. 61101
[illegible]	Barnes Mfg. Co., Mansfield, O. 44901
[illegible]	Wakefield Eng, Inc, Wakefield, Mass. 01880
[illegible]	Clevite Corp., Cleveland, O. 44110
[illegible]	Digitron Co, Pasadena, Calif
[illegible]	Eagle Signal (E.W. Bliss Co.), Baraboo, Wisc.
[illegible]	Avnet Corp, Culver City, Calif. 90230
[illegible]	Fairchild Camera, Mountain View, Calif
[illegible]	Birtcher Corp, No. Los Angeles, Calif
[illegible]	Amer Semicond, Arlington Hts, Ill. 60004
[illegible]	Bodine Corp, Bridgeport, Conn. 06605
[illegible]	Bodine Electric Co, Chicago, Ill. 60618
[illegible]	Cont Device Corp, Hawthorne, Calif.
[illegible]	State Labs Inc, N.Y., N.Y. 10003
[illegible]	Borg Inst., Delavan, Wisc 53115
[illegible]	Vemaline Prod Co., Franklin Lakes, N.J.
[illegible]	G.E. Semiconductor, Buffalo, N.Y.
[illegible]	Star-Tronics Inc, Georgetown, Mass 01830
[illegible]	Burgess Battery Co, Freeport, Ill.
[illegible]	Burndy Corp, Norwalk, Conn. 06852
[illegible]	C.T.S. of Berne, Inc, Berne, Ind. 46711
[illegible]	Chandler Evans Corp, W. Hartford, Conn.
[illegible]	National Semiconductor, Danbury, Conn.
[illegible]	Crystalonics, Cambridge, Mass 02140
[illegible]	RCA, Woodbridge, N.J.
[illegible]	Clarostat Mfg Co, Inc, Dover, N.H. 03820
[illegible]	Dickson Electronics, Scottsdale, Ariz.
[illegible]	Solitron Devices, Tappan, N.Y. 10983
[illegible]	ITT Semiconductors, W. Palm Beach, Fla.
[illegible]	Cornell-Dubilier Electric Co., Newark, N.J.
[illegible]	Corning Glass Works, Corning, N.Y.
[illegible]	General Instrument Corp, Hicksville, N.Y.
[illegible]	Microdot Magnetics Inc, Los Angeles, Calif.
[illegible]	ITT, Semiconductor Div, Lawrence, Mass.
[illegible]	Cutler-Hammer Inc, Milwaukee, Wisc. 53233
[illegible]	Spruce Pine Mica Co, Spruce Pine, N.C.
[illegible]	Indiana General Corp, Oglesby, Ill. 61348
[illegible]	Singer Co, Diehl Div, Somerville, N.J.
[illegible]	Voltronics Corp, Hanover, N.J. 07936
[illegible]	Illinois Tool Works, Paxton Div, Chicago, Ill.
[illegible]	Computer Diode Corp, S. Fairlawn, N.J. 07410
[illegible]	Cabtron Corp., Chicago, Ill. 60622
[illegible]	LRC Electronics, Horseheads, N.Y.
[illegible]	Electra Mfg Co, Independence, Kansas 67301
[illegible]	KMC Semiconductor Corp., Long Valley, N.J. 07853
[illegible]	Fafnir Bearing Co, New Britain, Conn.
[illegible]	UID Electronics Corp, Hollywood, Fla.
[illegible]	Avnet Electronics Corp, Franklin Park, Ill.
[illegible]	G.E., Schenectady, N.Y. 12305
[illegible]	G.E., Electronics Comp, Syracuse, N.Y.
[illegible]	G.E. (Lamp Div.), Nela Park, Cleveland, Ohio
[illegible]	General Radio Co, W. Concord, Mass. 01781
[illegible]	American Zettler Inc, Costa Mesa, Calif.
[illegible]	Hayman Mfg Co, Kenilworth, N.J.
[illegible]	Hoffman Electronics Corp, El Monte, Calif.
[illegible]	Beckman Instruments Inc, Cedar Grove, N.J. 07009
[illegible]	I.B.M., Armonk, New York
[illegible]	Jensen Mfg. Co, Chicago, Ill. 60638
[illegible]	G.E. Comp, Owensboro, Ky. 42301
[illegible]	Koehler Mfg. Co., Marlboro, Mass. 01752
[illegible]	Constanta Co, Mont., Ill, Que.
[illegible]	P.R. Mallory & Co Inc, Indianapolis, Ind.
[illegible]	Marlin-Rockwell Corp, Jamestown, N.Y.
[illegible]	Honeywell Inc, Minneapolis, Minn. 55408
[illegible]	Muter Co, Chicago, Ill. 60638
[illegible]	National Co, Inc, Melrose, Mass. 02176
[illegible]	Norma-Hoffman, Stamford, Conn. 06904
[illegible]	RCA, New York, N.Y. 10020
[illegible]	Raytheon Mfg Co, Waltham, Mass. 02154
[illegible]	Sangamo Electric Co, Springfield, Ill. 62705
[illegible]	Shallcross Mfg Co, Selma, N.C.
[illegible]	Shure Brothers, Inc, Evanston, Ill.
[illegible]	Sprague Electric Co, N. Adams, Mass
[illegible]	Thomas and Betts Co, Elizabeth, N.J. 07207
[illegible]	TRW Inc, (Accessories Div), Cleveland, Ohio
[illegible]	Torrington Mfg Co, Torrington, Conn.
[illegible]	Union Carbide Corp, New York, N.Y. 10017
[illegible]	United-Carr Fastener Corp, Boston, Mass.
[illegible]	Victoreen Instrument Co, Inc, Cleveland, O.
[illegible]	Ward Leonard Electric Co, Mt. Vernon, N.Y.
[illegible]	Westinghouse (Lamp Div), Bloomfield, N.J.
[illegible]	Weston Instruments, Newark, N.J.
[illegible]	Atlantic-India Rubber, Chicago, Ill. 60607
[illegible]	Amperite Co, Union City, N.J. 07087
[illegible]	Belden Mfg Co, Chicago, Ill. 60644
[illegible]	Bronson, Homer D. Co, Beacon Falls, Conn.
[illegible]	Cambridge Thermionic Corp, Camb. Mass. 02138
[illegible]	Canfield, H.O. Co, Clifton Forge, Va. 24422
[illegible]	Bussman (McGraw Eidson), St. Louis, Mo.
[illegible]	ITT Cannon Elec, L.A., Calif. 90031
[illegible]	Centralab, Inc, Milwaukee, Wisc. 53212
[illegible]	Continental Carbon Co, Inc, New York, N.Y.
[illegible]	Crescent Box Corp, E. Phila, Penn. 19134
[illegible]	Coto Coil Co Inc, Providence, R.I.
[illegible]	Chicago Miniature Lamp Works, Chicago, Ill.
[illegible]	Cinch Mfg Co, Chicago, Ill. 60624
[illegible]	Darnell Corp, Ltd, Downey, Calif. 90241
[illegible]	Electro Motive Mfg Co, Wilmington, Conn.
[illegible]	Nytronics Inc, Berkeley Heights, N.J. 07922
[illegible]	Dialight Co, Brooklyn, N.Y. 11237
[illegible]	General Instr Corp, Newark, N.J. 07104
[illegible]	Drake Mfg Co, Chicago, Ill. 60656
[illegible]	Hugh H. Eby Inc, Philadelphia, Penn. 19144
[illegible]	Elastic Stop Nut Corp, Union, N.J. 07083
[illegible]	Erie Technological Products Inc, Erie, Penn.
[illegible]	Beckman Inc, Fullerton, Calif 92634
[illegible]	Amperex Electronics Co, Hicksville, N.Y.
[illegible]	Carling Electric Co, W. Hartford, Conn.
[illegible]	Elco Resistor Co, New York, N.Y.
[illegible]	JFD Electronics Corp, Brooklyn, N.Y. 11219
[illegible]	Heinemann Electric Co, Trenton, N.J.
[illegible]	Industrial Condenser Corp, Chicago, Ill. 60618
[illegible]	Amphenol Corp, Danbury, Conn. 06810
[illegible]	E.F. Johnson Co, Waseca, Minn. 56093
[illegible]	IRC Inc, Philadelphia, Penn. 19108
[illegible]	Kulka Electric Corp, Mt. Vernon, N.Y.
[illegible]	Lafayette Industrial Electronics, Jamaica, N.Y.
[illegible]	Linden and Co, Providence, R.I.
[illegible]	Littelfuse, Inc, Des Plaines, Ill. 60016
[illegible]	Lord Mfg Co, Erie, Penn. 16512
[illegible]	Mallory Electric Corp, Detroit, Mich. 48204
[illegible]	James Millen Mfg. Co., Malden, Mass. 02148
[illegible]	Mueller Electric Co., Cleveland, Ohio 44114
[illegible]	National Tube Co, Pittsburg, Penn.
[illegible]	Oak Mfg Co, Crystal Lake, Ill.
[illegible]	Patton MacGuyer Co, Providence, R.I.
[illegible]	Pass-Seymour, Syracuse, N.Y.
[illegible]	Pierce Roberts Rubber Co, Trenton, N.J.
[illegible]	Positive Lockwasher Co, Newark, N.J.
[illegible]	American Machine & Foundry Co, Princton, Ind. 47570
[illegible]	Ray-O-Vac Co, Madison, Wisc.
[illegible]	TRW, Electronic Comp, Camden, N.J. 08103
[illegible]	General Instruments Corp, Brooklyn, N.Y.
[illegible]	Shakeproof (Ill. Took Works), Elgin, Ill. 60120
[illegible]	Sigma Instruments Inc, S. Braintree, Mass.
[illegible]	Stackpole Carbon Co, St. Marys, Penn.
[illegible]	Tinnerman Products, Inc, Cleveland, Ohio
[illegible]	RCA, Rec Tube & Semicond, Harrison, N.J.
[illegible]	Wiremold Co, Hartford, Conn. 06110
[illegible]	Zierick Mfg Co, New Rochelle, N.Y.
[illegible]	Tektronix Inc, Beaverton, Ore. 97005
[illegible]	Preston Fastener, Toledo, Ohio
[illegible]	Vickers Inc, St. Louis, Mo.
[illegible]	Electronic Industries Assoc, Washington, D.C.
[illegible]	Sprague Products Co, No. Adams, Mass.
[illegible]	Motorola Inc., Franklin Park, Ill. 60131
[illegible]	Standard Oil Co, Lafeyette, Ind.
[illegible]	Bourns Inc, Riverside, Calif. 92506
[illegible]	Sylvania Electric Products Inc, N.Y. 10017
[illegible]	Air Filter Corp, Milwaukee, Wisc. 53218
[illegible]	Hammarlund Co, Inc, New York, N.Y.
[illegible]	Beckman Instruments, Inc, Fullerton, Calif.
[illegible]	Pure Carbon Co., St. Marys, Penn. 15857
[illegible]	International Instrument, Orange, Conn.
[illegible]	Grayhill Inc, LaGrange, Ill. 60525
[illegible]	Isolantite Mfg Corp, Stirling, N.J. 07980
[illegible]	Military Specifications
[illegible]	Joint Army-Navy Specifications
[illegible]	Fenwal Electronics, Framingham, Mass. 01701
[illegible]	International Rectifier Corp, El Segundo, Calif 90245
[illegible]	Columbus Electronics Corp, Yonkers, N.Y.
[illegible]	Filtron Co, Flushing, L.I., N.Y. 11354
[illegible]	Ledex Inc, Dayton, Ohio 45402
[illegible]	Barry-Wright Corp, Watertown, Mass.
[illegible]	Sylvania Elec Prod, Emporium, Penn
[illegible]	Indiana Pattern & Model Works, LaPort, Ind
[illegible]	Switchcraft Inc, Chicago, Ill. 60630
[illegible]	Metals & Controls Inc, Attleboro, Mass.
[illegible]	Milwaukee Resistor Co, Milwaukee, Wisc
[illegible]	Rotron Mfg. Co. Inc., Woodstock, N.Y. 12498
[illegible]	Messner Mfg. (Maguire Ind) Mt. Carmel, Ill
[illegible]	Carr Fastener Co, Cambridge, Mass
[illegible]	Victory Engineering, Springfield, N.J. 07081
[illegible]	Bearing Specialty Co, San Francisco, Calif
[illegible]	Solar Electric Corp, Warren, Penn
[illegible]	Union Carbide Corp, New York, N.Y. 10017
[illegible]	National Electronics Inc, Geneva, Ill.
[illegible]	TRW Capacitor Div, Ogallala, Nebr
[illegible]	Lehigh Metal Prods, Cambridge, Mass. 02140
[illegible]	TA Mfg Corp, Los Angeles, Calif.
[illegible]	Precision Metal Prods, Stoneham, Mass. 02180
[illegible]	RCA (Elect. Comp & Dev), Harrison, N.J.
[illegible]	REC Corp, New Rochelle, N.Y. 10801
[illegible]	Cont Electronics Corp, Brooklyn, N.Y. 11222
[illegible]	Cutler-Hammer Inc, Lincoln, Ill.
[illegible]	Gould Nat. Batteries Inc, Trenton, N.J.
[illegible]	Cornell-Dubilier, Fuquay-Varina, N.C.
[illegible]	K & G Mfg Co, New York, N.Y.
[illegible]	Holtzer-Cabot Corp, Boston, Mass
[illegible]	United Transformer Co, Chicago, Ill.
[illegible]	Mallory Capacitor Co, Indianapolis, Ind.
[illegible]	Gulton Industries, Inc, Metuchen, N.J. 08840
[illegible]	Westinghouse Electric Corp, Boston, Mass.
[illegible]	Hardware Products Co, Reading, Penn. 19602
[illegible]	Continental Wire Corp, York, Penn. 17405
[illegible]	ITT (Cannon Electric Inc), Salem, Mass.
[illegible]	Gerber Mfg. Co, Mishawaka, Ind.
[illegible]	Johanson Mfg Co, Boonton, N.J. 07005
[illegible]	Augat Inc, Attleboro, Mass. 02703
[illegible]	Chandler Co, Wethersfield, Conn. 06109
[illegible]	Dale Electronics Inc, Columbus, Nebr.
[illegible]	Elco Corp, Willow Grove, Penn.
[illegible]	General Instruments, Inc, Dallas, Texas
[illegible]	Mephisto Tool Co. Inc, Hudson, N.Y. 12534
[illegible]	Honeywell Inc, Freeport, Ill.
[illegible]	Electra Insul Corp, Woodside, L.I., N.Y
[illegible]	E.G.&G., Boston, Mass.
[illegible]	Ampex Corp, Redwood City, Calif. 94063
[illegible]	Sylvania Elect Prods, Inc, Woburn, Mass.
[illegible]	R. & C. Mfg. Co. of Penn. Inc, Ramey, Penn.
[illegible]	Cramer Products Co, New York, N.Y. 10013
[illegible]	Raytheon Co, Components Div, Quincy, Mass.
[illegible]	Tung Sol Electric Inc, Newark, N.J.
[illegible]	Weston Instruments Inc, Archibald, Penn. 18403
[illegible]	Dickson Co., Chicago, Ill. 60619
[illegible]	Atlas Industrial Corp., Brooklyn, N.H.
[illegible]	Garde Mfg. Co., Cumberland, R.I.
[illegible]	Quality Components Inc, St. Mary's, Penn.
[illegible]	Alco Electronics Mfg Co, Lawrence, Mass.
[illegible]	Continental Connector Corp, Woodside, N.Y.
[illegible]	Vitramon, Inc, Bridgeport, Conn.
[illegible]	Methode Mfg Co, Chicago, Ill.
[illegible]	General Electric Co, Schenectady, N.Y.
[illegible]	Anaconda Amer Brass Co, Torrington, Conn.
[illegible]	Hi-Q Div. of Aerovox Corp, Orlean, N.Y.
[illegible]	Texas Instruments Inc, Dallas, Texas 75209
[illegible]	Thordarson-Meissner, Mt. Carmel, Ill.
[illegible]	Microwave Associates Inc, Burlington, Mass.
[illegible]	Amphenol Corp, Janesville, Wisc. 53545
[illegible]	Military Standards
[illegible]	Models Inc, North Bergen, N.J.
[illegible]	Sealectro Corp, Mamaroneck, N.Y. 10544
[illegible]	Compar Inc, Burlingame, Calif.
[illegible]	North Hills Electronics Inc., Glen Cove, N.Y.
[illegible]	Metavac Inc, Flushing, N.Y. 11358
[illegible]	Transitron Electronics Corp, Melrose, Mass.
[illegible]	Varian, Palo Alto, Calif. 94303
[illegible]	Atlee Corp, Winchester, Mass. 01890
[illegible]	Delevan Electronics Corp, E. Aurora, N.Y.

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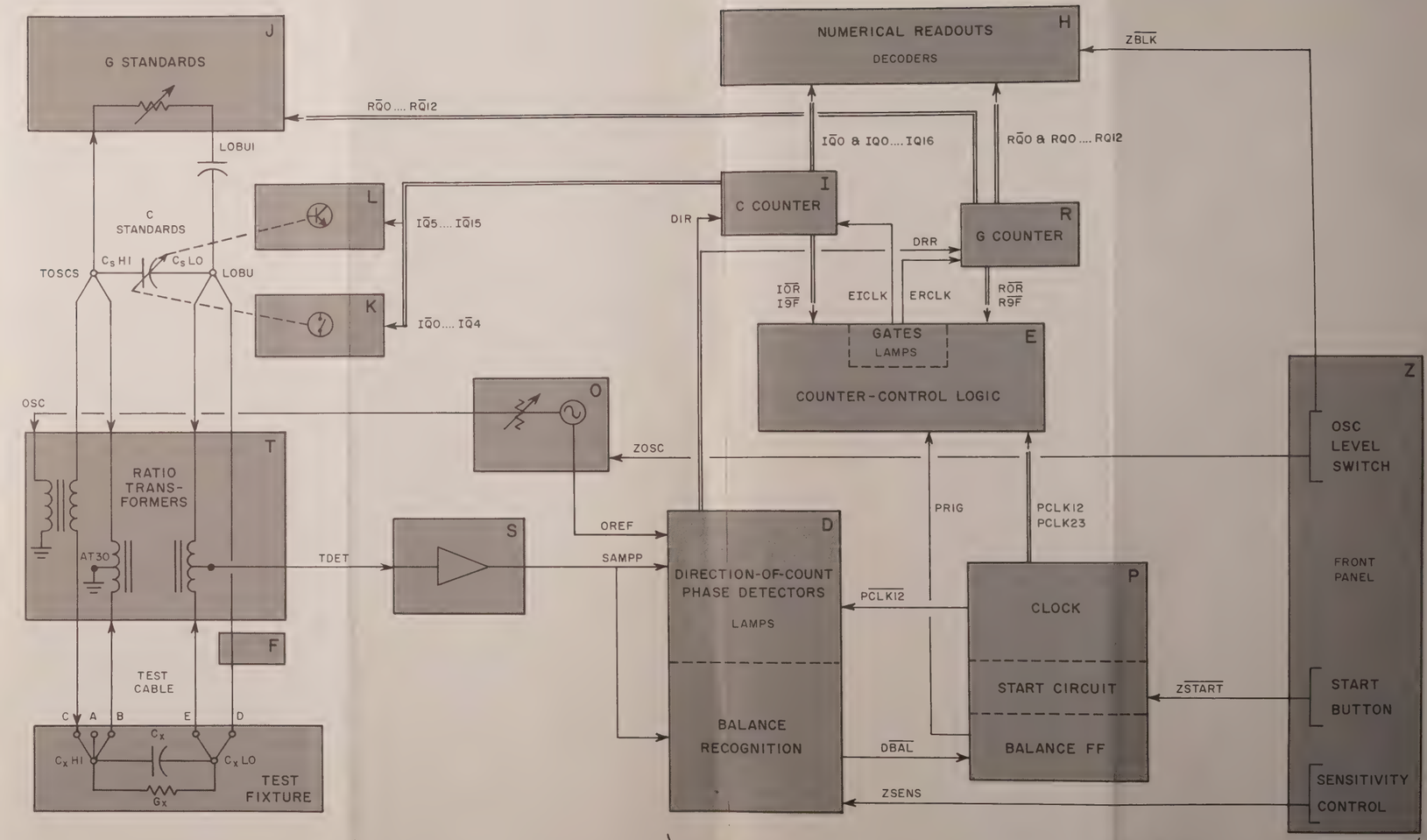
Figure 6-1 →



1682-21

Figure 6-1. Basic bridge and automatic balancing loop shown as a functional flow diagram. Signals are identified between boards.

FEDERAL MANUFACTURER'S CODE

From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) as supplemented through August, 1968.

Code	Manufacturer
00192	Jones Mfg. Co, Chicago, Illinois
00194	Walsco Electronics Corp, L.A., Calif.
00434	Schweber Electronics, Westburg, L.I., N.Y.
00656	Aerovox Corp, New Bedford, Mass.
01009	Alden Products Co, Brockton, Mass.
01121	Allen-Bradley, Co, Milwaukee, Wisc.
01236	Leeds Radio Company, N.Y.
01255	Litton Industries Inc, Beverly Hills, Calif.
01295	Texas Instruments, Inc, Dallas, Texas
02114	Ferroxcube Corp, Saugerties, N.Y. 12477
02606	Fenwal Lab Inc, Morton Grove, Ill.
02660	Amphenol Electron Corp, Broadview, Ill.
02768	Fastex, Des Plaines, Ill. 60016
03042	Carter Ink Co., Camb. Mass. 02142
03508	G.E. Semicon Prod, Syracuse, N.Y. 13201
03636	Grayburne, Yonkers, N.Y. 10701
03888	Pyrofilm Resistor Co, Cedar Knolls, N.J.
03911	Clairex Corp, New York, N.Y. 10001
04009	Arrow-Hart & Hegeman, Hart., Conn. 06106
04643	Digitronics Corp., Albertson, N.Y. 11507
04713	Motorola, Phoenix, Ariz. 85008
05170	Engr'd Electronics, Santa Ana, Calif. 92702
05624	Barber-Colman Co, Rockford, Ill. 61101
05748	Barnes Mfg. Co., Mansfield, O. 44901
05820	Wakefield Eng, Inc, Wakefield, Mass. 01880
06743	Clevite Corp., Cleveland, O. 44110
07126	Digitron Co, Pasadena, Calif.
07127	Eagle Signal (E.W. Bliss Co.), Baraboo, Wisc.
07261	Avnet Corp, Culver City, Calif. 90230
07263	Fairchild Camera, Mountain View, Calif.
07387	Birtcher Corp, No. Los Angeles, Calif.
07595	Amer Semicond, Arlington Hts, Ill. 60004
07828	Bodine Corp, Bridgeport, Conn. 06605
07829	Bodine Electric Co, Chicago, Ill. 60618
07910	Cont Device Corp, Hawthorne, Calif.
07983	State Labs Inc, N.Y., N.Y. 10003
07999	Borg Inst., Delavan, Wisc. 53115
08730	Vemaline Prod Co., Franklin Lakes, N.J.
09213	G.E. Semiconductor, Buffalo, N.Y.
09408	Star-Tronics Inc, Georgetown, Mass. 01830
09823	Burgess Battery Co, Freeport, Ill.
09922	Burndy Corp, Norwalk, Conn. 06852
11236	C.T.S. of Berne, Inc, Berne, Ind. 46711
11599	Chandler Evans Corp, W. Hartford, Conn.
12040	National Semiconductor, Danbury, Conn.
12498	Crystalonics, Cambridge, Mass. 02140
12672	RCA, Woodbridge, N.J.
12697	Clarostat Mfg Co, Inc, Dover, N.H. 03820
12954	Dickson Electronics, Scottsdale, Ariz.
13327	Solitron Devices, Tappan, N.Y. 10983
14433	ITT Semiconductors, W. Palm Beach, Fla.
14655	Cornell-Dubilier Electric Co., Newark, N.J.
14674	Corning Glass Works, Corning, N.Y.
14936	General Instrument Corp, Hicksville, N.Y.
15116	Microdot Magnetics Inc, Los Angeles, Calif.
15238	ITT, Semiconductor Div, Lawrence, Mass.
15605	Cutler-Hammer Inc, Milwaukee, Wisc. 53233
16037	Spruce Pine Mica Co, Spruce Pine, N.C.
16636	Indiana General Corp, Oglesby, Ill. 61348
17771	Singer Co, Diehl Div, Somerville, N.J.
18736	Voltronics Corp, Hanover, N.J. 07936
19396	Illinois Tool Works, Pakton Div, Chicago, Ill.
19048	Computer Diode Corp, S. Fairlawn, N.J. 07410
19617	Cabtron Corp., Chicago, Ill. 60622
19644	LRC Electronics, Horseheads, N.Y.
19701	Electra Mfg Co, Independence, Kansas 67301
20754	KMC Semiconductor Corp., Long Valley, N.J. 07853
21335	Fafnir Bearing Co, New Briton, Conn.
22753	UID Electronics Corp, Hollywood, Fla.
23342	Avnet Electronics Corp, Franklin Park, Ill.
24446	G.E., Schenectady, N.Y. 12305
24454	G.E., Electronics Comp, Syracuse, N.Y.
24455	G.E. (Lamp Div.), Nela Park, Cleveland, Ohio
24655	General Radio Co, W. Concord, Mass. 01781
26806	American Zettlet Inc, Costa Mesa, Calif.
28520	Hayman Mfg Co, Kenilworth, N.J.
28959	Hoffman Electronics Corp, El Monte, Calif.
30646	Beckman Instruments Inc, Cedar Grove, N.J. 07009
30874	I.B.M., Armonk, New York
32001	Jensen Mfg. Co, Chicago, Ill. 60638
33173	G.E. Comp, Owensboro, Ky. 42301
34141	Koehler Mfg. Co. Inc., Marlboro, Mass. 01752
35929	Constanta Co, Mont. 19, Que.
37942	P.R. Mallory & Co Inc, Indianapolis, Ind.
38443	Marlin-Rockwell Corp, Jamestown, N.Y.
40931	Honeywell Inc, Minneapolis, Minn. 55408
42190	Muter Co, Chicago, Ill. 60638
42498	National Co, Inc, Melrose, Mass. 02176
43991	Norma-Hoffman, Stanford, Conn. 06904
49671	RCA, New York, N.Y. 10020
49956	Raytheon Mfg Co, Waltham, Mass. 02154
53021	Sangamo Electric Co, Springfield, Ill. 62705
54294	Shallcross Mfg Co, Selma, N.C.
54715	Shure Brothers, Inc, Evanston, Ill.
56289	Sprague Electric Co, N. Adams, Mass.
59730	Thomas and Betts Co, Elizabeth, N.J. 07207
59875	TRW Inc, (Accessories Div), Cleveland, Ohio
60399	Torrington Mfg Co, Torrington, Conn.
61637	Union Carbide Corp, New York, N.Y. 10017
61864	United-Carr Fastener Corp, Boston, Mass.
63060	Victoreen Instrument Co, Inc, Cleveland, O.
63743	Ward Leonard Electric Co, Mt. Vernon, N.Y.
65083	Westinghouse (Lamp Div), Bloomfield, N.J.
65092	Weston Instruments, Newark, N.J.
70485	Atlantic-India Rubber, Chicago, Ill. 60607
70563	Amperite Co, Union City, N.J. 07087
70903	Belden Mfg Co, Chicago, Ill. 60644
71126	Bronson, Homer D, Co, Beacon Falls, Conn.
71279	Cambridge Thermionic Corp, Camb. Mass. 02138
71294	Canfield, H.O. Co, Clifton Forge, Va. 24422
71400	Bussman (McGraw Eidson), St. Louis, Mo.
71468	ITT Cannon Elec, L.A., Calif. 90031
71590	Centralab, Inc, Milwaukee, Wisc. 53212
71666	Continental Carbon Co, Inc, New York, N.Y.
71729	Crescent Box Corp, E. Phila, Penn. 19134
71707	Coto Coil Co Inc, Providence, R.I.
71744	Chicago Miniature Lamp Works, Chicago, Ill.
71785	Cinch Mfg Co, Chicago, Ill. 60624
71823	Darnell Corp, Ltd, Downey, Calif. 90241
72136	Electro Motive Mfg Co, Wilmington, Conn.
72259	Nytronics Inc, Berkeley Heights, N.J. 07922
72619	Dialight Co, Brooklyn, N.Y. 11237
72699	General Instr Corp, Newark, N.J. 07104
72765	Drake Mfg Co, Chicago, Ill. 60656
72825	Hugh H. Eby Inc, Philadelphia, Penn. 19144
72962	Elastic Stop Nut Corp, Union, N.J. 07083
72982	Erie Technological Products Inc, Erie, Penn.
73138	Beckman Inc, Fullerton, Calif. 92634
73445	Amperex Electronics Co, Hicksville, N.Y.
73559	Carling Electric Co, W. Hartford, Conn.
73690	Elco Resistor Co, New York, N.Y.
73899	JFD Electronics Corp, Brooklyn, N.Y. 11219
74193	Heinemann Electric Co, Trenton, N.J.
74861	Industrial Condenser Corp, Chicago, Ill. 60618
74868	Amphenol Corp, Danbury, Conn. 06810
74970	E.F. Johnson Co, Waseca, Minn. 56093
75042	IRC Inc, Philadelphia, Penn. 19108
75382	Kulka Electric Corp, Mt. Vernon, N.Y.
75491	Lafayette Industrial Electronics, Jamaica, N.Y.
75608	Linden and Co, Providence, R.I.
75915	Littelfuse, Inc, Des Plaines, Ill. 60016
76005	Lord Mfg Co, Erie, Penn. 16512
76149	Mallory Electric Corp, Detroit, Mich. 48204
76487	James Millen Mfg. Co., Malden, Mass. 02148
76545	Mueller Electric Co., Cleveland, Ohio 44114
76684	National Tube Co, Pittsburg, Penn.
76854	Oak Mfg Co, Crystal Lake, Ill.
77147	Patton MacGuyer Co, Providence, R.I.
77166	Pass-Seymour, Syracuse, N.Y.
77263	Pierce Roberts Rubber Co, Trenton, N.J.
77339	Positive Lockwasher Co, Newark, N.J.
77342	American Machine & Foundry Co, Princton, Ind. 47570
77542	Ray-O-Vac Co, Madison, Wisc.
77630	TRW, Electronic Comp, Camden, N.J. 08103
77638	General Instruments Corp, Brooklyn, N.Y.
78189	Shakeproof (Ill. Took Works), Elgin, Ill. 60120
78277	Sigma Instruments Inc, S. Braintree, Mass.
78488	Stackpole Carbon Co, St. Marys, Penn.
78553	Tinnerman Products, Inc, Cleveland, Ohio
79089	RCA, Rec Tube & Semicond, Harrison, N.J.
79725	Wiremold Co, Hartford, Conn. 06110
79963	Zierick Mfg Co, New Rochelle, N.Y.
80009	Tektronix Inc, Beaverton, Ore. 97005
80030	Prestole Fastener, Toledo, Ohio
80048	Vickers Inc, St. Louis, Mo.
80131	Electronic Industries Assoc, Washington, D.C.
80183	Sprague Products Co, No. Adams, Mass.
80211	Motorola Inc., Franklin Park, Ill. 60131
80258	Standard Oil Co, Lafeyette, Ind.
80294	Bourns Inc, Riverside, Calif. 92506
80368	Sylvania Electric Products Inc, N.Y. 10017
80431	Air Filter Corp, Milwaukee, Wisc. 53218
80583	Hammarlund Co, Inc, New York, N.Y.
80740	Beckman Instruments, Inc, Fullerton, Calif.
80894	Pure Carbon Co., St. Marys, Penn. 15857
81030	International Instrument, Orange, Conn.
81073	Grayhill Inc, LaGrange, Ill. 60525
81143	Isolantite Mfg Corp, Stirling, N.J. 07980
81349	Military Specifications
81350	Joint Army-Navy Specifications
81386	Fenwal Electronics, Framingham, Mass. 01701
81483	International Rectifier Corp, El Segundo, Calif. 90245
81751	Columbus Electronics Corp, Yonkers, N.Y.
81831	Filtron Co, Flushing, L.I., N.Y. 11354
81840	Ledex Inc, Dayton, Ohio 45402
81860	Barry-Wright Corp, Watertown, Mass.
82219	Sylvania Elec Prod, Emporium, Penn.
82273	Indiana Pattern & Model Works, LaPort, Ind.
82389	Switchcraft Inc, Chicago, Ill. 60630
82647	Metals & Controls Inc, Attleboro, Mass.
82807	Milwaukee Resistor Co, Milwaukee, Wisc.
82877	Rotron Mfg. Co. Inc., Woodstock, N.Y. 12498
83033	Meissner Mfg, (Maguire Ind) Mt. Carmel, Ill.
83058	Carr Fastener Co, Cambridge, Mass.
83186	Victory Engineering, Springfield, N.J. 07081
83361	Bearing Specialty Co, San Francisco, Calif.
83587	Solar Electric Corp, Warren, Penn.
83740	Union Carbide Corp, New York, N.Y. 10017
83781	National Electronics Inc, Geneva, Ill.
84411	TRW Capacitor Div, Ogallala, Nebr.
84835	Lehigh Metal Prods, Cambridge, Mass. 02140
84971	TA Mfg Corp, Los Angeles, Calif.
86577	Precision Metal Prods, Stoneham, Mass. 02180
86684	RCA (Elect. Comp & Dev), Harrison, N.J.
86687	REC Corp, New Rochelle, N.Y. 10801
86800	Cont Electronics Corp, Brooklyn, N.Y. 11222
88140	Cutler-Hammer Inc, Lincoln, Ill.
88219	Gould Nat. Batteries Inc, Trenton, N.J.
88419	Cornell-Dubilier, Fuquay-Varina, N.C.
88627	K & G Mfg Co, New York, N.Y.
89482	Holtzer-Cabot Corp, Boston, Mass.
89665	United Transformer Co, Chicago, Ill.
90201	Mallory Capacitor Co, Indianapolis, Ind.
90634	Gulton Industries, Inc, Metuchen, N.J. 08840
90750	Westinghouse Electric Corp, Boston, Mass.
90952	Hardware Products Co, Reading, Penn. 19602
91032	Continental Wire Corp, York, Penn. 17405
91146	ITT (Cannon Electric Inc), Salem, Mass.
91210	Gerber Mfg. Co, Mishawaka, Ind.
91293	Johanson Mfg Co, Boonton, N.J. 07005
91506	Augat Inc, Attleboro, Mass. 02703
91598	Chandler Co, Wethersfield, Conn. 06109
91637	Dale Electronics Inc, Columbus, Nebr.
91662	Elco Corp, Willow Grove, Penn.
91719	General Instruments, Inc, Dallas, Texas
91916	Mephisto Tool Co. Inc, Hudson, N.Y. 12534
91929	Honeywell Inc, Freeport, Ill.
92519	Electra Insul Corp, Woodside, L.I., N.Y.
92678	E.G.&G., Boston, Mass.
92739	Ampex Corp, Redwood City, Calif. 94063
93332	Sylvania Elect Prods, Inc, Woburn, Mass.
93618	R. & C. Mfg. Co. of Penn. Inc, Ramey, Penn.
93916	Cramer Products Co, New York, N.Y. 10013
94144	Raytheon Co, Components Div, Quincy, Mass.
94154	Tung Sol Electric Inc, Newark, N.J.
94271	Weston Instruments Inc, Archibald, Penn. 18403
94589	Dickson Co., Chicago, Ill. 60619
94800	Atlas Industrial Corp., Brooklyn, N.H.
95076	Garde Mfg. Co., Cumberland, R.I.
95121	Quality Components Inc, St. Mary's, Penn.
95146	Alco Electronics Mfg Co, Lawrence, Mass.
95238	Continental Connector Corp, Woodside, N.Y.
95275	Vitramon, Inc, Bridgeport, Conn.
95354	Methode Mfg Co, Chicago, Ill.
95412	General Electric Co, Schenectady, N.Y.
95794	Anaconda Amer Brass Co, Torrington, Conn.
96095	Hi-Q Div. of Aerovox Corp, Orlean, N.Y.
96214	Texas Instruments Inc, Dallas, Texas 75209
96256	Thordarson-Meissner, Mt. Carmel, Ill.
96341	Microwave Associates Inc, Burlington, Mass.
96791	Amphenol Corp, Janesville, Wisc. 53545
96906	Military Standards
97684	Models Inc, North Bergen, N.J.
98291	Sealectro Corp, Mamaroneck, N.Y. 10544
98474	Compar Inc, Burlingame, Calif.
98821	North Hills Electronics Inc., Glen Cove, N.Y.
99117	Metavac Inc, Flushing, N.Y. 11358
99180	Transitron Electronics Corp, Melrose, Mass.
99313	Varian, Palo Alto, Calif. 94303
99378	Atlee Corp, Winchester, Mass. 01890
99800	Delevan Electronics Corp, E. Aurora, N.Y.

Figure 6-1 →

Table 6-1 (Cont)
SIGNAL INDEX (1682)

Interface Signals*	Interior Signals†	Description	Block Diag.	Principal Addresses△
	ZSING	"0" when mode switch at SING MEAS, or REMOTE and SING = "0". Controls nothing; cf. SING.	—	M-Z-23E
	ZSETO	"1" while SET ZERO button pressed or QSETO = "0". Sets counters (hence standards; readouts) to zero.	6-4	M-Z-37C; M-I-12E.
	ZSEZR	"0" while SET ZERO button pressed. Makes DBAL and PRIG both "0", to inhibit counting.	6-4	M-Z-41C
	ZSTART	"0" when START button pressed or EXT START circuit closed (as by switch in 1682-P1 Test Fixture). "0" transition is start command, must be held 20 μs min, may be held indefinitely, but must be "1" at least 75 ms before next start by NSING2 or ZSTART; otherwise like QSING1.	6-1	M-Z-36C; M-P-30E.
	ZTRACK	"0" when mode switch at TRACKING, or REMOTE and TRACK = "0". Holds PRIG = "1" (unless STOP, DBAL, or ZSEZR = "0") and holds PABORT = "1". Enables VMR generator regardless of state of balance FF.	6-4	M-Z-21E; M-P-41E.
	ZT-series	ZT1 . . . ZT6. TEST modes selected by mode switch only. All make PCLK12 = PVMR, so bridge counts slowly, depending on RATE control. All effects of ZTRACK being "0" are valid (but ZTRACK = "1").	6-4	M-Z-20C, -19C, -21C, -22C, -23C, -24C respectively; or M-P-42E, -43E, -51C, -50C, -51E, -50E, respectively.

"0" state	DIR	D-DS2	DRR	D-DS1	EICLK	ERCLK
ZT1	0	on	—	—	normal	0
ZT2	1	off	(1)	(off)	normal	0
ZT3	—	—	0	on	0	normal
ZT4	(1)	(off)	1	off	0	normal
ZT5/6	All normal; bridge seeks balance.					

	ZVAR	"0" when mode switch at VAR MEAS RATE, or REMOTE and VAR = "0". Enables VMR generator to trigger start circuitry (cf. PVMR).	6-4	M-Z-22E; M-P-31E.
	ZVARR	Analog link between freq-determining ckt of VMR generator and RATE control, which is 0-1 MΩ returned to −15 V (or in STOP position, switch closed to ground).	6-4	M-Z-35C; M-P-32E.

* Rear-panel connectors: α = AUXILIARY, β = BIAS VOLTAGE, δ = DATA OUTPUT.

†Initial letter indicates source board or subassembly.

△ Letters followed by hyphens are board designations; where there are 2 hyphens, the address is where one board plugs into another.

PAINT

If the front panel is scratched and needs retouching, use paint described by Federal Standard 595 as gray, 26492.

MECHANICAL PARTS LIST

Qnt	Fig Ref	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
FRONT						
2	1	Handle.	5360-2017	24655	5360-2017	
1	2	Cabinet gasket.	5331-2182	24655	5331-2182	
1	3	Indicator Window, nF/UNBAL./ pF/RANGE.	1682-7411	24655	1682-7411	
1	4	Indicator Window, mΩ/μΩ.	1682-7421	24655	1682-7421	
1	5	Front window (polarized).	1683-7000	24655	1683-7000	
3	6	Knob-asm., SENSITIVITY; BIAS, 0/1; RATE, including retainer 5220-5402.	5520-5221	24655	5520-5221	
1	7	Toggle switch, A-S8, INTERNAL/ REMOTE.	7910-0790	95146	MST-105D	
1	8	Test cable asm., includes:	1682-2310	24655	1682-2310	
3		Connector, BNC	4220-1810	02660	69475	
2		Connector, GR 874	0874-4583	24655	0874-4583	
1	9	Cable-mounting block.	1682-7000	24655	1682-7000	
1	10	Signal jack, A-J7, EXT START.	4260-1050	82389	112B	
4	11	Knob asm., OSC LEVEL; BIAS switch; RANGE; mode, including retainer 5220-5402.	5500-5221	24655	5500-5221	
1	12	Toggle switch, A-S50, POWER/OFF.	7910-1300	04009	83053-SA	5930-909-3510
1	13	Bench cabinet asm.,	4173-4004*	24655	4173-4004	
1	14	Incl. Base, tilt, without hardware;	4171-1077	24655	4171-1077	
1		Incl. Foot asm., U-shaped bail;	4171-1012	24655	4171-1012	
1		Not incl. Rear cover, picture-frame shaped.	4171-8164	24655	4171-8164	
2	15	Pushbutton switch, A-S5, SET ZERO; A-S6, START	7870-1511	81073	4001 N.O.	
REAR						
1	1	Cover plate (wide).	1682-8390	24655	1682-8390	
2	2	Multiple sockets, 1 each a part of N and Q-board assemblies.	4230-4035	93916	57-40350	
1	3	Cover plate (narrow).	1682-8360	24655	1682-8360	
8	4	Slide block	4171-7050	24655	4171-7050	
2	5	BNC Jack, A-J8, BIAS VOLTAGE; A-J15, EXT METER.	4230-2301	09408	UG-1094A/U	
3	6	Outer shaft for A-C20, A-C23, A-C24, zero adjustments, used with: bushing.	1682-7060	24655	1682-7060	
			7270-4910	24655	7270-4910	
1	7	Slide switch, A-S10, zero offset.	7910-0771			
2	8	Fuse-mounting device.	5650-0100	71400	HKP-H	5920-284-7144
1	9	Slide switch, A-S51, line-voltage selector.	7910-0831	42190	4603	
1	10	Power plug, A-J55.	4240-0600	24655	4240-0600	5935-816-0254
1	—	Top shield cover.	1682-8211	24655	1682-8211	
1	—	Bottom shield cover.	1682-8201	24655	1682-8201	

*Refer to Table 2-3 for another breakdown, Table 2-1 for rack mounting cabinet.

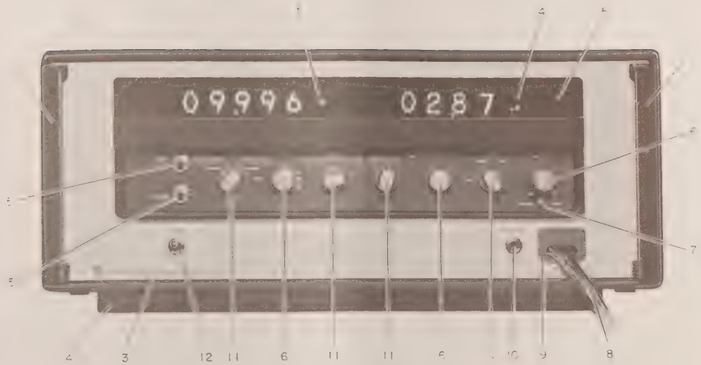
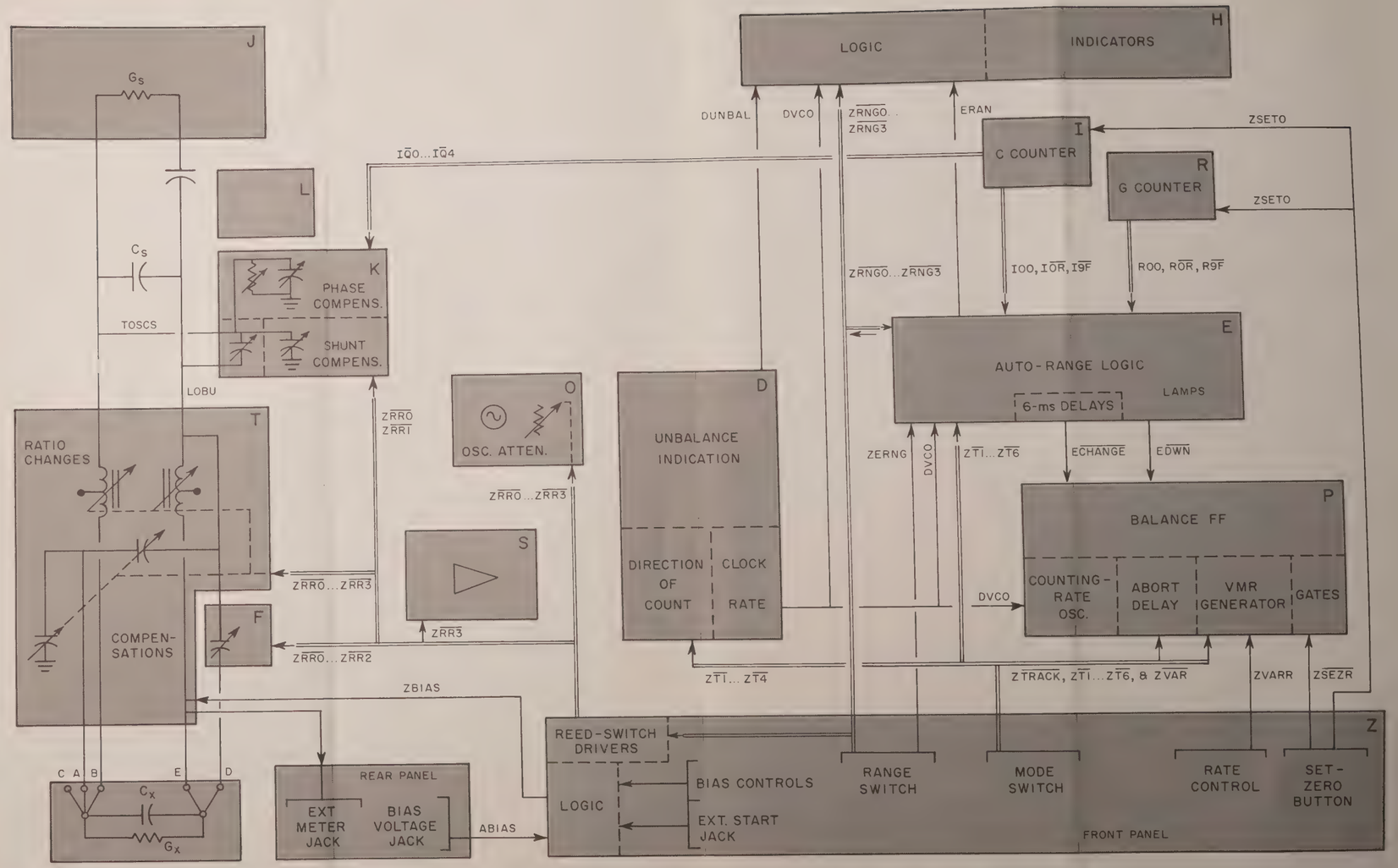


Figure 6-2. Front view; mechanical replaceable parts are identified.

Figure 6-3. Rear view; mechanical replaceable parts are identified.



1682-22

Figure 6-4. Range, mode, and other special features shown as a supplementary functional flow diagram. Signals are identified between boards.

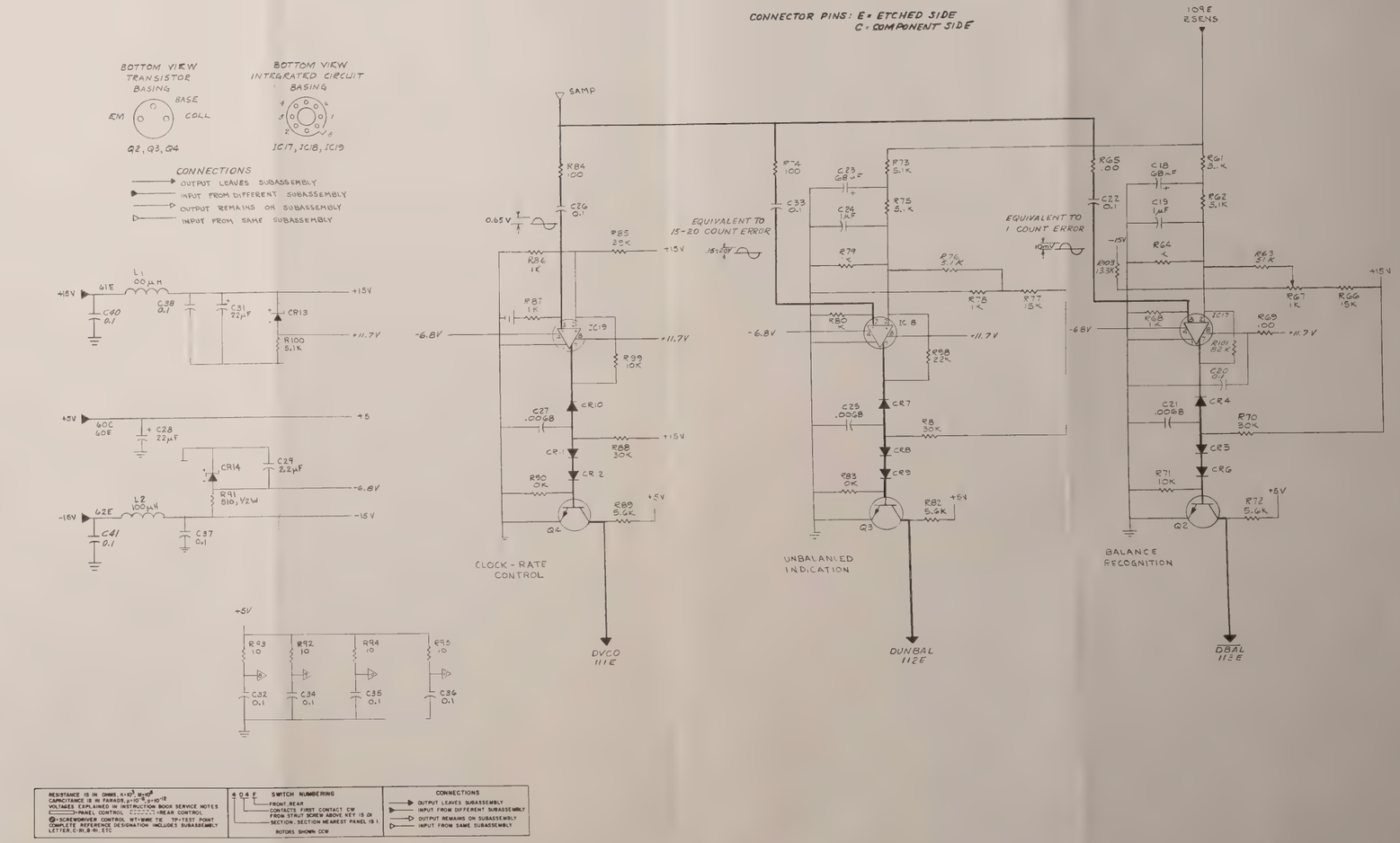


Figure 6-5. Detector diagram, part 1. D_1

Figure 6-5 (D) →

ELECTRICAL PARTS LIST

D BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
	COMPLETE BOARD				
D	Detector Board	1682-4765	24655	1682-4765	
	CAPACITORS				
C1	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C2	Ceramic, 150 pF	4404-1155	72982	831, 150 pF 10%	
C3	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C4	Ceramic, 2.2 μF	4400-2080	80183	5C13, 2.2 μF 20%	
C5	Ceramic, 75 pF	4404-0755	72982	831, 75 pF 5%	
C6 and C7	Ceramic, 2.2 μF	4400-2080	80183	5C13, 2.2 μF 20%	
C8	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C9	Ceramic, 75 pF	4404-0755	72982	831, 75 pF 5%	
C10 and C11	Ceramic, 2.2 μF	4400-2080	80183	5C13, 2.2 μF 20%	
C12 thru C14	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C15	Ceramic, 75 pF	4404-0755	72982	831, 75 pF 5%	
C16 and C17	Ceramic, 2.2 μF	4400-2080	80183	5C13, 2.2 μF 20%	
C18	Tantalum, 68 μF	4450-5615	80183	150D686X0015R2	
C19	Ceramic, 1 μF	4400-2070	80183	5C13, 1 μF 20%	5910-083-6445
C20	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C21	Ceramic, .0068 μF	4406-2689	72982	811, .0068 μF +80-20%	
C22	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C23	Tantalum, 68 μF	4450-5615	80183	150D686X0015R2	
C24	Ceramic, 1 μF	4400-2070	80183	5C13, 1 μF 20%	5910-083-6445
C25	Ceramic, .0068 μF	4406-2689	72982	811, .0068 μF +80-20%	
C26	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C27	Ceramic, .0068 μF	4406-2689	72982	811, .0068 μF +80-20%	
C28	Tantalum, 22 μF	4450-5300	56289	150D226X0015B2	5910-752-4270
C29	Ceramic, 2.2 μF	4400-2080	80183	5C13, 2.2 μF 20%	
C30 and C31	Tantalum, 22 μF	4450-5300	56289	150D226X0015B2	5910-752-4270
C32 thru C38	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C39	Ceramic, 1 μF	4400-2070	80183	5C13, 1 μF 20%	5910-083-6445
C40 and C41	Ceramic, .1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
	DIODES				
CR1 thru CR12	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR13	Type 1N746	6083-1005	07910	1N746	5960-984-3570
CR14	Type 1N957B	6083-1009	07910	1N957B	
	INDUCTORS				
L1 and L2	Choke, molded	4300-3500	99800	2890-42, 100 μH 10%	
	INTEGRATED CIRCUITS				
IC1	Digital	5431-9622	96214	SN15862N	
IC2	Digital	5431-9442	96214	SN15844N	
IC3 and IC4	Digital	5431-9452	96214	SN15845N	
IC5	Digital	5431-9362	96214	SN15836N	
IC6 and IC7	Digital	5431-9482	96214	SN15848N	
IC8 thru IC11	Digital	5431-8200	96214	SN74H00N	
IC12 thru IC16	Linear	5432-3028	79089	CA3028A	
IC17 thru IC19	Linear	5432-7101	07263	U5B771039X	
	LAMPS				
DS1 and DS2	State Indicator	5600-1071	17460	2309	
	RESISTORS				
R1	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R2	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R3	Comp., 5.1 kΩ ±5%	6099-2515	75042	BTS, 5.1 kΩ ±5%	5905-683-2241
R4 and R5	Comp., 510 Ω, ±5%	6099-1515	75042	BTS, 510 Ω 5%	5905-801-8272
R6	Comp., 3 kΩ, ±5%	6099-2305	75042	BTS, 3 kΩ 5%	5905-682-4097
R7	Pot., Wire Wound, 10 kΩ	6051-3109	02660	2600 PC, 10 kΩ 10%	
R8	Comp., 3.9 kΩ, ±5%	6099-2395	75042	BTS, 3.9 kΩ 5%	
R9	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422

ELECTRICAL PARTS LIST (cont)

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
	RESISTORS (Cont)				
R10	Comp., 3.3 kΩ, ±5%	6099-2335	75042	BTS, 3.3 kΩ 5%	5905-681-9969
R11	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R12	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R13	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R14	Comp., 560 Ω, ±5%	6099-1565	75042	BTS, 560 Ω 5%	
R15	Comp., 680 Ω, ±5%	6099-1685	75042	BTS, 680 Ω 5%	
R16	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R17	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R18 and R19	Comp., 20 Ω, ±5%	6099-0205	75042	BTS, 20 Ω 5%	
R20	Comp., 3 kΩ, ±5%	6099-2305	75042	BTS, 3 kΩ 5%	5905-682-4097
R21	Pot., Wire Wound, 10 kΩ	6051-3109	02660	2600 PC, 10 kΩ, 10%	
R22	Comp., 3.9 kΩ, ±5%	6099-2395	75042	BTS, 3.9 kΩ 5%	
R23	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R24	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R25	Comp., 3.3 kΩ, ±5%	6099-2335	75042	BTS, 3.3 kΩ 5%	5905-681-9969
R26 and R27	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R28	Comp., 560 Ω, ±5%	6099-1565	75042	BTS, 560 Ω 5%	
R29	Comp., 680 Ω, ±5%	6099-1685	75042	BTS, 680 Ω 5%	
R30	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R31	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R32 and R33	Comp., 20 Ω, ±5%	6099-0205	75042	BTS, 20 Ω 5%	
R34	Comp., 150 Ω, ±5%	6099-1155	75042	BTS, 150 Ω 5%	5905-683-2243
R35	Comp., 2 kΩ, ±5%	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370
R36	Comp., 750 Ω, ±5%	6099-1755	75042	BTS, 750 Ω 5%	
R37	Comp., 5.1 kΩ ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R38	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R39	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R40	Comp., 10 kΩ ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R41	Comp., 330 kΩ, ±5%	6099-4335	75042	BTS, 330 kΩ 5%	
R42	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R43	Comp., 2 kΩ, ±5%	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370
R44	Comp., 750 Ω, ±5%	6099-1755	75042	BTS, 750 Ω 5%	
R45	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R46	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R47	Comp., 360 Ω	6099-1365	75042	BTS, 360 Ω ±5%	
R48	Comp., 3.9 kΩ ±5%	6099-2395	75042	BTS, 3.9 kΩ 5%	
R49	Comp., 1.2 kΩ, ±5%	6099-2125	75042	BTS, 1.2 kΩ 5%	
R50	Comp., 3 kΩ, ±5%	6099-2305	75042	BTS, 3 kΩ 5%	5905-682-4097
R51	Comp., 3.3 kΩ, ±5%	6099-2335	75042	BTS, 3.3 kΩ 5%	5905-681-9969
R52	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R53	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R54	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R55	Comp., 560 Ω, ±5%	6099-1565	75042	BTS, 560 Ω 5%	
R56	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R57	Comp., 680 Ω, ±5%	6099-1685	75042	BTS, 680 Ω 5%	
R58	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R59 and R60	Comp., 20 Ω, ±5%	6099-0205	75042	BTS, 20 Ω 5%	
R61 and R62	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R63	Comp., 51 kΩ, ±5%	6099-3515	75042	BTS, 51 kΩ 5%	5905-682-4103
R64	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R65	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R66	Film, 15 kΩ, ±1%	6350-2150	75042	CEB, 15 kΩ 1%	5905-583-6233
R67	Pot., cermet 1 kΩ	6049-0186	80294	3009P, 1 kΩ	
R68	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R69	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R70	Comp., 30 kΩ, ±5%	6099-3305	75042	BTS, 30 kΩ 5%	5905-803-2908
R71	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R72	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R73	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R74	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R75 and R76	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R77	Film, 15 kΩ, ±1%	6350-2150	75042	CEB, 15 kΩ 1%	5905-583-6233
R78	Film, 1 kΩ ±1%	6350-1100	75042	CEB, 1 kΩ ±1%	5905-892-7018
R79 and R80	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R81	Comp., 30 kΩ, ±5%	6099-3305	75042	BTS, 30 kΩ 5%	5905-803-2908
R82	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R83	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R84	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R85	Comp., 39 kΩ, ±5%	6099-3395	75042	BTS, 39 kΩ 5%	5905-686-3358
R86 and R87	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R88	Comp., 30 kΩ, ±5%	6099-3305	75042	BTS, 30 kΩ 5%	5905-803-2908

ELECTRICAL PARTS LIST (cont)

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
	RESISTORS (Cont)				
R89	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R90	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R91	Comp., 510 Ω, ±5%	6100-1515	01121	RC20GF511J	5905-279-3511
R92 thru R95	Comp., 10 Ω, ±5%	6099-0105	75042	BTS, 10 Ω 5%	5905-809-8596
R96	Comp., 51 kΩ, ±5%	6099-3515	75042	BTS, 51 kΩ 5%	5905-682-4103
R97	Pot., wire wound, 20 kΩ	6051-3209	02660	2600 P.C., 20 kΩ 10%	
R98	Comp., 22 kΩ, ±5%	6099-3225	75042	BTS, 22 kΩ 5%	5905-687-0002
R99	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R100	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R101	Comp., 82 kΩ, ±5%	6099-3825	75042	BTS, 82 kΩ 5%	
R102	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R103	Film, 13.3 kΩ ±1%	6350-2133	75042	CEB, 13.3 kΩ 1%	5905-581-1019
	TRANSISTORS				
Q1 thru Q4	Type 2N4275	8210-1126	07263	2N4275	

NOTE: This view is the side where parts are mounted; they are shown as areas of wavy lines. Etched circuitry (if any) on this side appears gray; on the other side, black. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is not the part number.

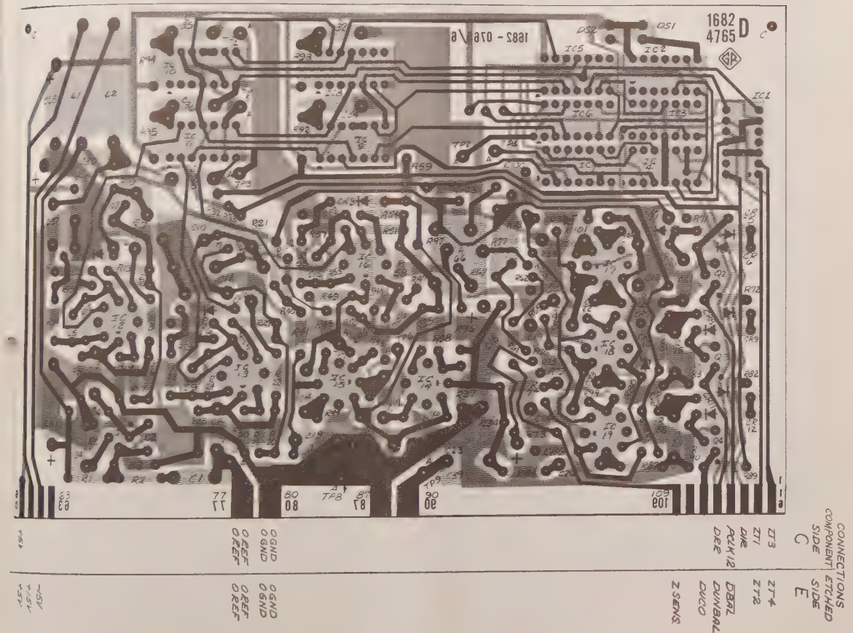


Figure 6-6. D-board assembly, showing etched circuit (P/N 1682-4765).

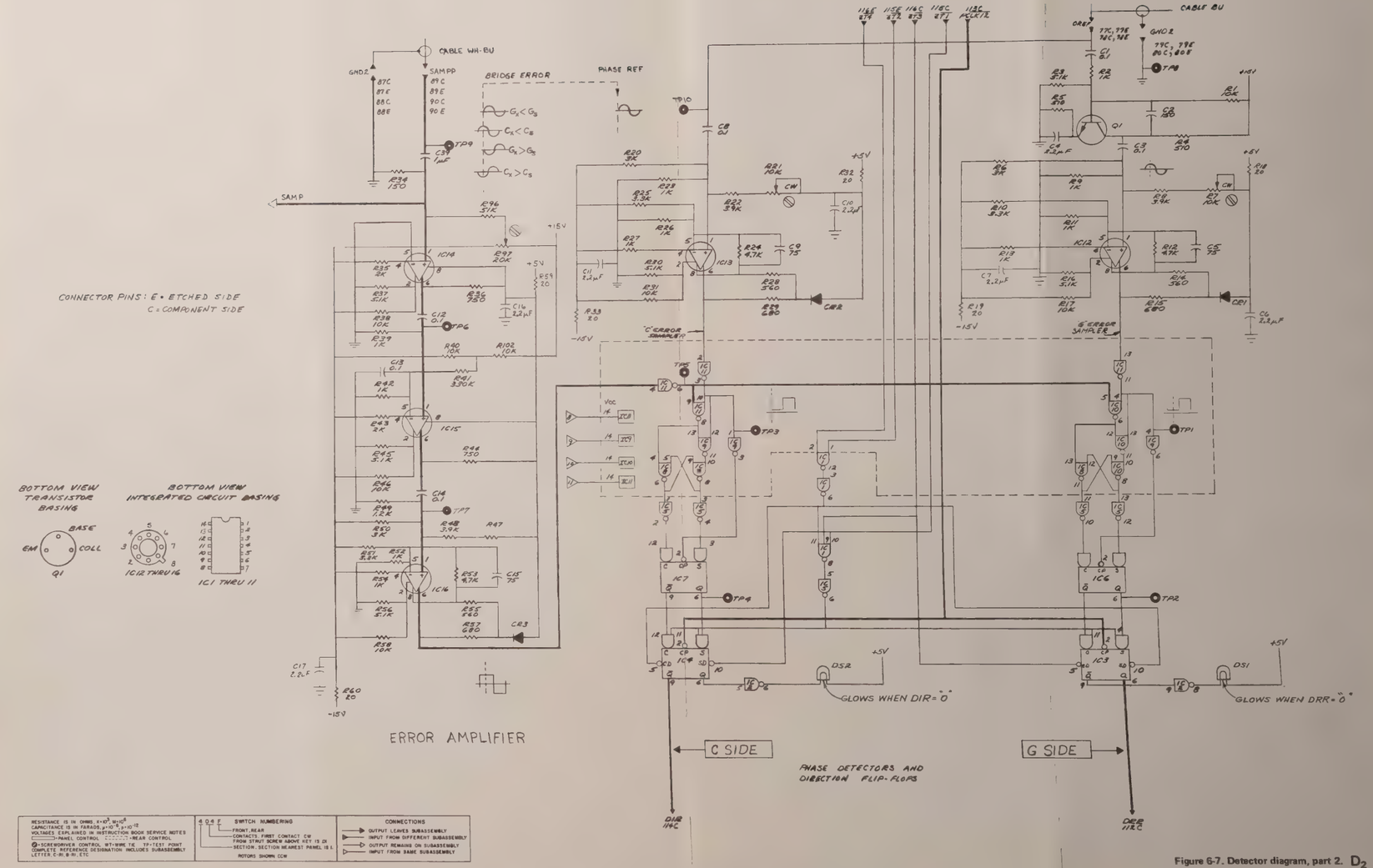


Figure 6-7. Detector diagram, part 2. D_2

ELECTRICAL PARTS LIST

E BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No
COMPLETE BOARD					
E	Counter-gate/Auto-range Board	1682-4720	24655	1682-4720	
CAPACITORS					
C1 thru C4	Ceramic, 0.22 μF	4400-2052	80183	5C13, .22 μF 20%	5910-974-5694
C5 and C6	Ceramic, 0.1 μF	4400-2050	80183	5C13, .1 μF 20%	5910-080-4646
DIODES					
CR1 thru CR12	Type 1N3604	6082-1001	24655	1N3604	5961-995-2199
CR14 thru CR18	Type 1N3604	6082-1001	24655	1N3604	5961-995-2199
INTEGRATED CIRCUITS					
IC1	Digital	5431-9099	96214	SN158099N	
IC2	Digital	5431-9492	96214	SN15849N	
IC3	Digital	5431-9622	96214	SN15862N	
IC4	Digital	5431-9442	96214	SN15844N	
IC7	Digital	5431-9622	96214	SN15862N	
IC9	Digital	5431-9482	96214	SN15848N	
IC10	Digital	5431-9632	96214	SN15863N	
IC11	Digital	5431-9302	96214	SN15830N	
IC12	Digital	5431-9442	96214	SN15844N	
IC13	Digital	5431-9462	96214	SN15846N	
IC14	Digital	5431-9492	96214	SN15849N	
IC16	Digital	5431-9093	96214	SN158093N	
IC17	Digital	5431-9362	96214	SN15836N	
IC18 and IC19	Digital	5431-9462	96214	SN15846N	
IC20	Digital	5431-9442	96214	SN15844N	
IC21	Digital	5431-9482	96214	SN15848N	
IC22	Digital	5431-9322	96214	SN15832N	
IC23	Digital	5431-9462	96214	SN15846N	
IC24	Digital	5431-9482	96214	SN15848N	
IC25 and IC26	Digital	5431-9322	96214	SN15832N	
IC27	Digital	5431-9372	96214	SN15837N	
IC28	Digital	5431-9322	96214	SN15832N	
LAMPS					
DS1 thru DS4	State Indicators	5600-1071	17460	2309	
DS6 and DS7	State Indicators	5600-1071	17460	2309	
RESISTORS					
R1 thru R3	Comp., 150 kΩ, ±5%	6099-4155	75042	BTS, 150 kΩ 5%	5905-686-9995
R4 and R5	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R6	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R7 thru R9	Comp., 150 kΩ, ±5%	6099-4155	75042	BTS, 150 kΩ 5%	5905-686-9995
R10 and R11	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R12	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
TRANSISTORS					
Q1 and Q2	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is not the part number.

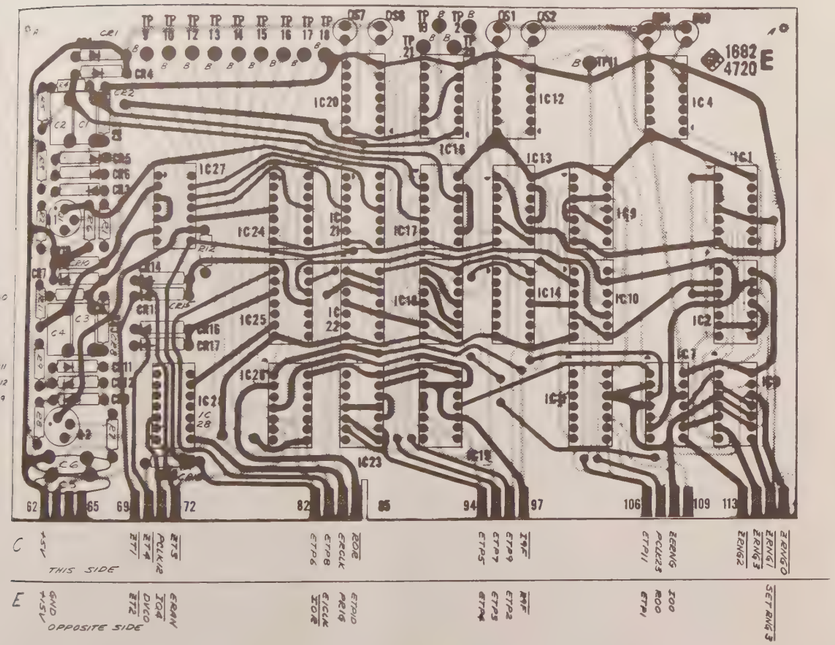
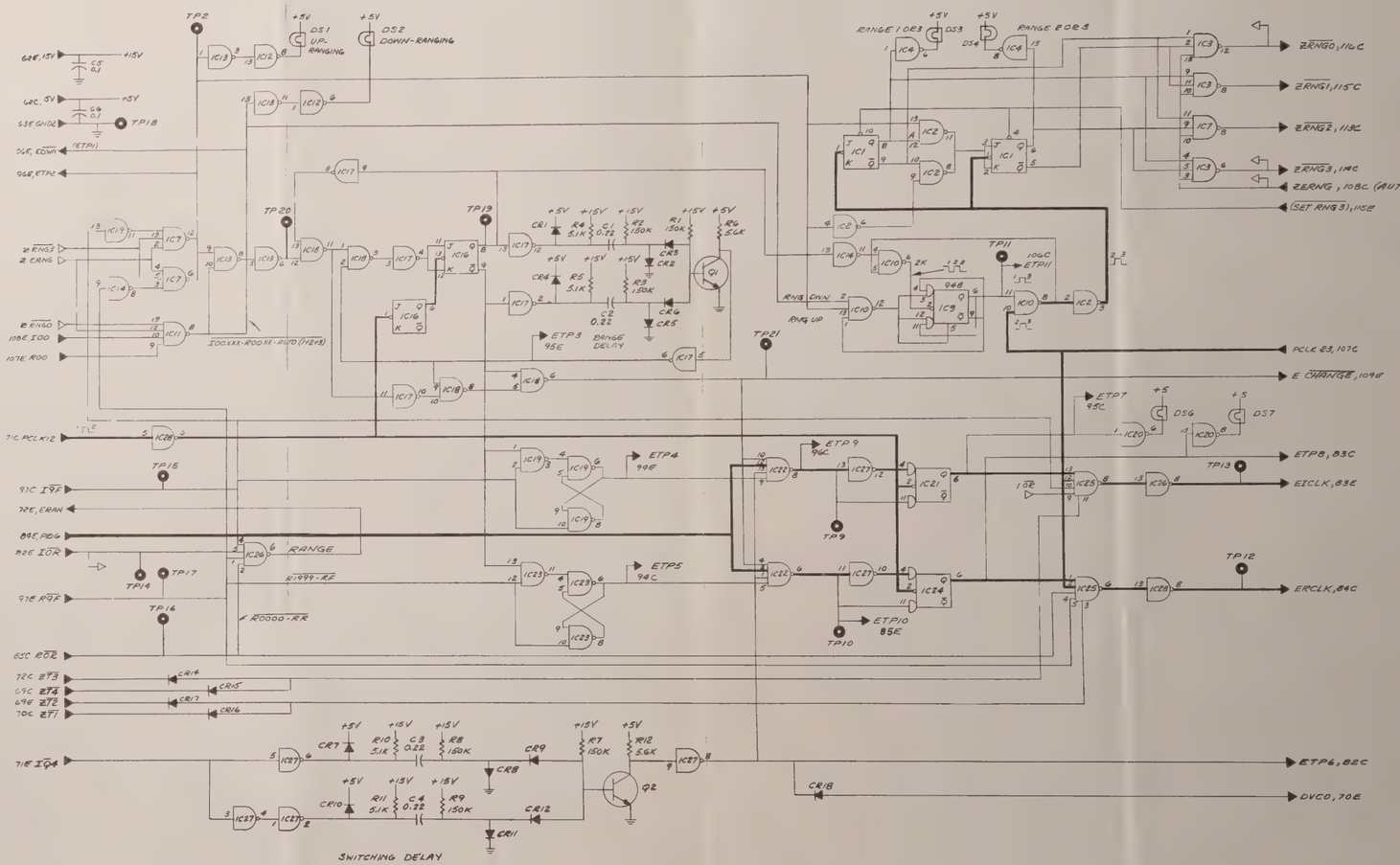


Figure 6-8. E-board assembly, showing etched circuit (P/N 1682-4720).



RESISTANCE IS IN OHMS, K=10³, M=10⁶
CAPACITANCE IS IN FARADS, μ=10⁻⁶, p=10⁻¹²
VOLTAGES EXPLAINED IN INSTRUCTION BOOK SERVICE NOTES
PANEL CONTROL
SCREWDRIVER CONTROL WT=WIRE TIE TP=TEST POINT
COMPLETE REFERENCE DESIGNATION INCLUDES SUBASSEMBLY LETTER, C-IH, R-IR, ETC
SWITCH NUMBERING
FRONT, REAR
CONTACTS, FIRST CONTACT CW FROM STRUT SCREW ABOVE KEY 1 S.01
SECTION, SECTION NEAREST PANEL IS 1.
ROTORS SHOWN CCW
CONNECTIONS
OUTPUT LEAVES SUBASSEMBLY
INPUT FROM DIFFERENT SUBASSEMBLY
OUTPUT REMAINS ON SUBASSEMBLY
INPUT FROM SAME SUBASSEMBLY

Figure 6-9. Counting gates and automatic range selector. E

ELECTRICAL PARTS LIST

F BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
F	Compensation Board	1682-4712	24655	1682-4712	
CAPACITORS					
C1	Ceramic, 0.1 µF	4403-4100	80131	CC63, .1 µF +80-20%	5910-974-5699
C2	Mica, 4700 pF ±1%	4600-1400	72136	DM-20 (4 CR)	
C3*	Mica, 1000 pF ±1%	4710-0100	14655	22A, .001 µF 1%	5910-068-0840
C4*	Mica, 499 pF ±1%	4710-0570	14655	22A, 499 pF 1%	
C5*	Mica, 1500 pF ±5%	4700-0690	14655	22A, 1500 pF 5%	
C7	Mica, 4700 pF ±1%	4600-1400	72136	DM-20 (4 CR)	
DIODES					
CR1 thru CR7	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
RELAYS					
K1L thru K3L	Reed Coils	6090-1130	71707	XU-8242-P	
K1S	Reed Switches	6090-1260	24655	6090-1260	
K2S and K3S	Reed Switches	6080-0800	30874	76586S	
RESISTOR					
R1	Comp., 180 Ω ±5%	6099-1185	75042	BTS, 180 Ω, 5%	5905-682-4107

*Indicated part is typical; final value is selected by calibration lab.

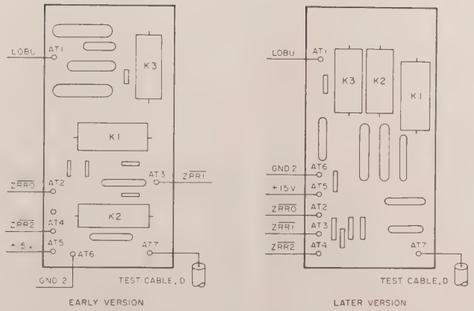


Figure 6-10. F-board layouts, early and later versions (circuit unchanged).

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

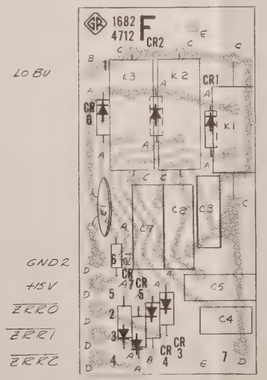
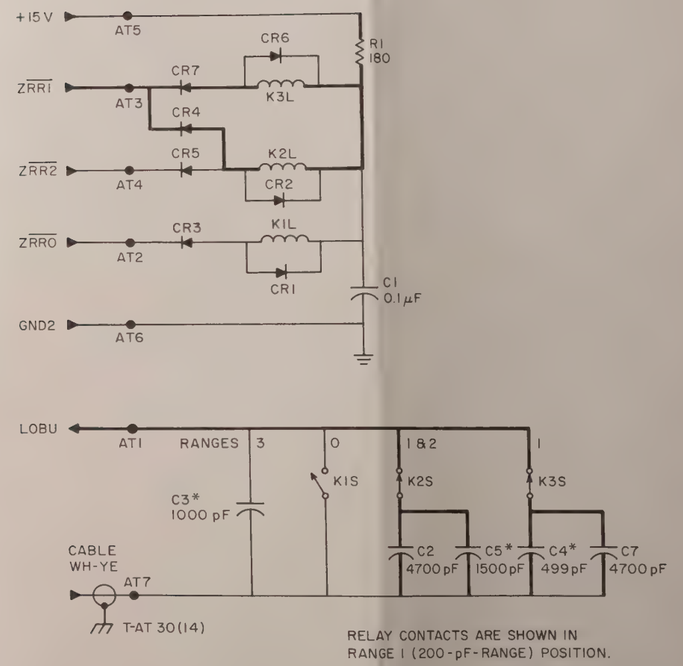


Figure 6-11. F-board assembly, showing etched circuit (P/N 1682-4712).



1682-35

*Indicated part is typical; final value is selected by calibration lab.

Figure 6-12. Compensation circuit diagram. F

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

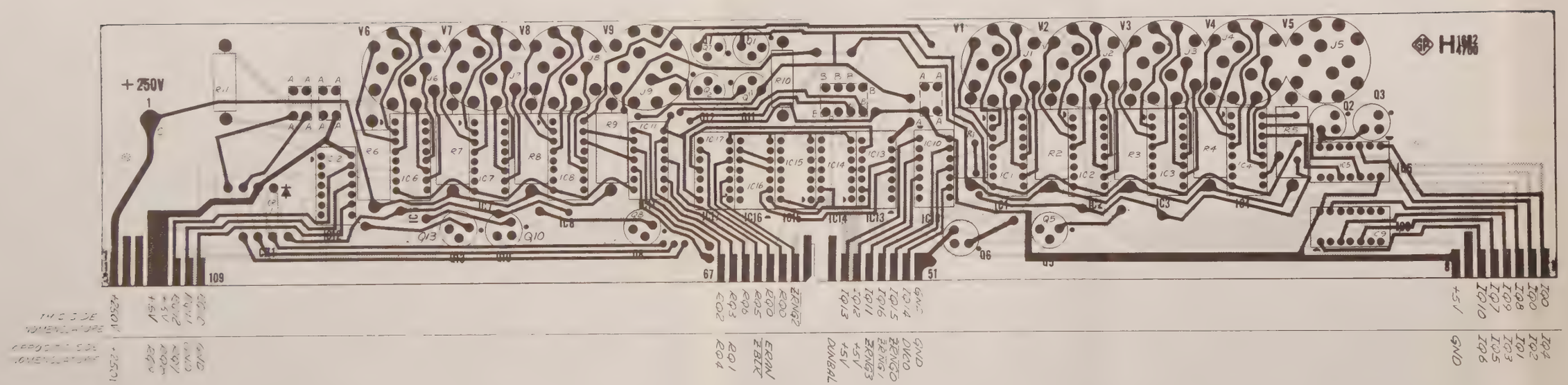


Figure 6-13. H-board assembly, showing etched circuit (P/N 1682-4700).

ELECTRICAL PARTS LIST

H BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No
COMPLETE BOARD*					
H	Display	1682-4700	24655	1682-4700	
DIODE					
CR1	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR2	Type 1N995	6082-1002	80368	1N995	5961-893-6762
INTEGRATED CIRCUITS					
IC1 thru IC4	Digital	5431-9602	07263	CμL 960	
IC5	Digital	5431-9362	96214	SN15836N	
IC6 thru IC8	Digital	5431-9602	07263	CμL 960	
IC9 thru IC12	Digital	5431-9362	96214	SN15836N	
IC13	Digital	5431-9462	96214	SN15846N	
IC14 and IC15	Digital	5431-9442	96214	SN15844N	
IC16	Digital	5431-9622	96214	SN15862N	
IC17	Digital	5431-9362	96214	SN15836N	
RESISTORS					
R1 thru R9	Comp., 30 kΩ, ±5%	6120-3305	01121	RC42GF303J	5905-171-1977
R10 and R11	Comp., 20 kΩ, ±5%	6110-3205	01121	RC32GF203J	5905-299-2021
SOCKETS					
J1 thru J9	Tube sockets	7540-3466	83781	RTS-14	
TRANSISTORS					
Q1	Type 2N3440	8210-1098	79089	2N3440	
Q2 and Q3	Type 2N4410	8210-1176	04713	2N4410	
Q5 thru Q8	Type 2N4410	8210-1176	04713	2N4410	
Q10 thru Q12	Type 2N4410	8210-1176	04713	2N4410	

*Not including Indicator Assemblies (below) nor Numerical Readout Tubes (page 6-2).

INDICATOR ASSEMBLIES (PLUGGED INTO H BOARD)				
	Cpt. assembly (includes next 4 items)	1682-2310	24655	1682-2310
	Etched board	1682-4795	24655	1682-4795
	Window: nF, pF, UNBAL, RANGE	1682-7411	24655	1682-7411
DS1 thru DS4	Lamps	5600-1070	17460	2334
DS7 and DS8	Lamps	5600-1070	17460	2334
	Cpt. assembly (includes next 3 items)	1682-2300	24655	1682-2300
	Etched board	1682-4785	24655	1682-4785
	Window: mΩ, μΩ	1682-7421	24655	1682-7421
DS5 and DS6	Lamps	5600-1070	17460	2334

Figure 6-14 (H) →

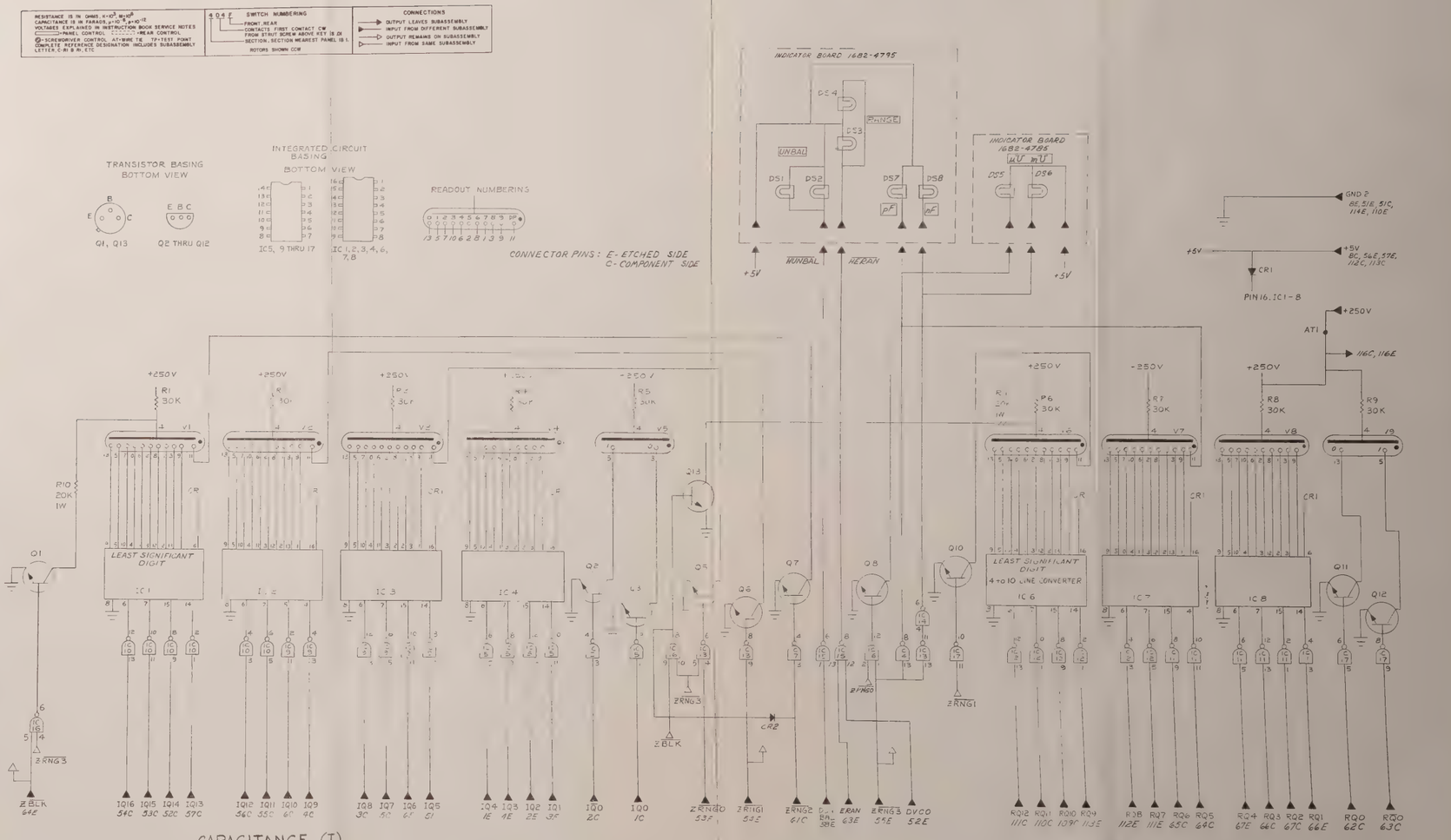


Figure 6-14. Display circuit diagram. H

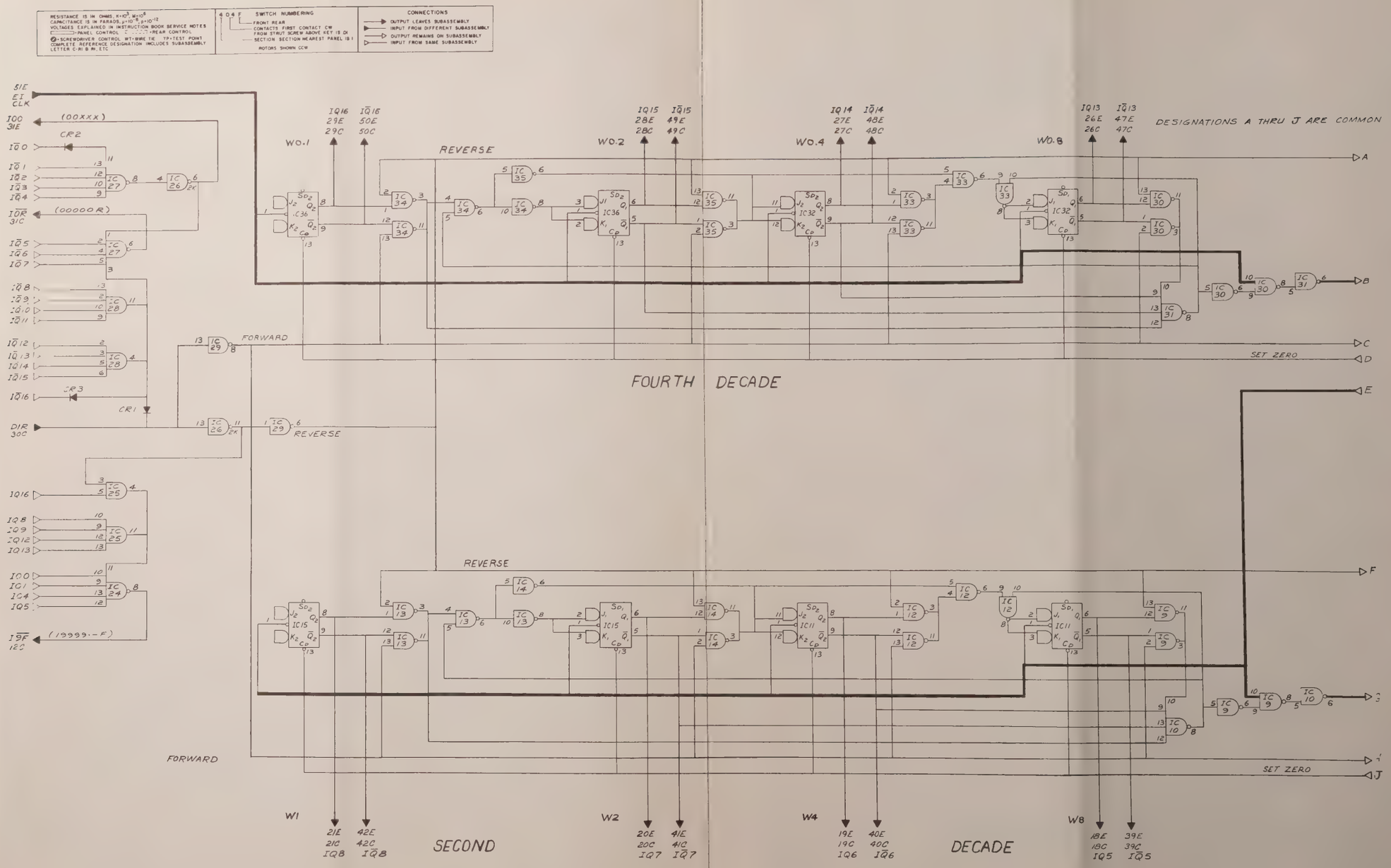


Figure 6-15 (I_1) →

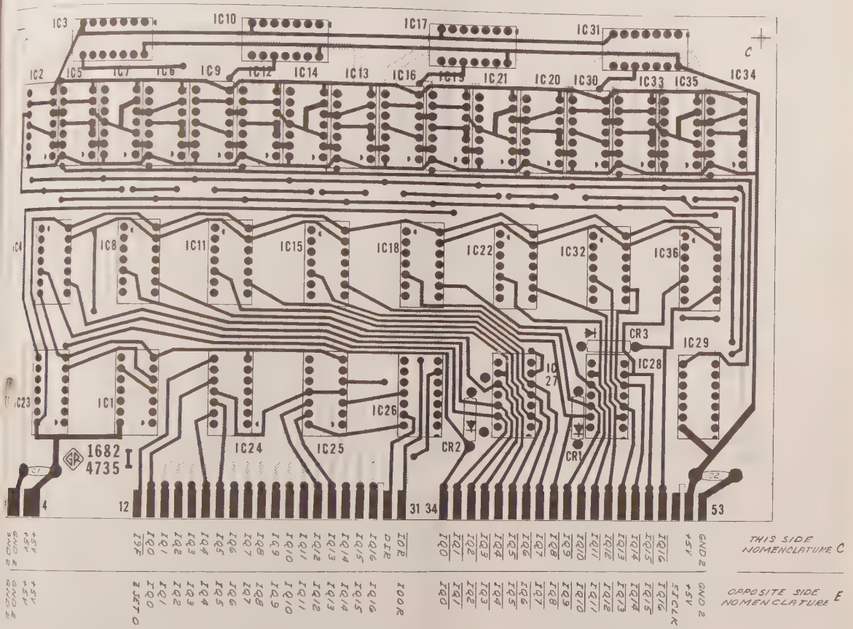
Figure 6-15. C-counter circuit diagram, part 1. I_1

ELECTRICAL PARTS LIST

1 BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
I	C Counter	1682-4735	24655	1682-4735	
CAPACITORS					
C1 and C2	Ceramic, +80-20%	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
DIODES					
CR1 thru CR3	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
INTEGRATED CIRCUITS					
IC1	Digital	5431-9452	96214	SN15845N	
IC2	Digital	5431-9492	96214	SN15849N	
IC3	Digital	5431-9322	96214	SN15832N	
IC4	Digital	5431-9099	96214	SN158099	
IC5 thru IC7	Digital	5431-9462	96214	SN15846N	
IC8	Digital	5431-9099	96214	SN158099	
IC9	Digital	5431-9492	96214	SN15849N	
IC10	Digital	5431-9322	96214	SN15832N	
IC11	Digital	5431-9099	96214	SN158099	
IC12 thru IC14	Digital	5431-9462	96214	SN15846N	
IC15	Digital	5431-9099	96214	SN158099	
IC16	Digital	5431-9492	96214	SN15849N	
IC17	Digital	5431-9322	96214	SN15832N	
IC18	Digital	5431-9099	96214	SN158099	
IC19 thru IC21	Digital	5431-9462	96214	SN15846N	
IC22	Digital	5431-9099	96214	SN158099	
IC23 and IC24	Digital	5431-9322	96214	SN15832N	
IC25	Digital	5431-9332	96214	SN15833N	
IC26	Digital	5431-9492	96214	SN15849N	
IC27	Digital	5431-9322	96214	SN15832N	
IC28	Digital	5431-9332	96214	SN15833N	
IC29	Digital	5431-9322	96214	SN15832N	
IC30	Digital	5431-9492	96214	SN15849N	
IC31	Digital	5431-9322	96214	SN15832N	
IC32	Digital	5431-9097	96214	SN158097	
IC33 thru IC35	Digital	5431-9462	96214	SN15846N	
IC36	Digital	5431-9097	96214	SN158097	

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.



THIS SIDE NOMENCLATURE C

OPPOSITE SIDE NOMENCLATURE E

Figure 6-16. I-board assembly, showing etched circuit (P/N 1682-4735).

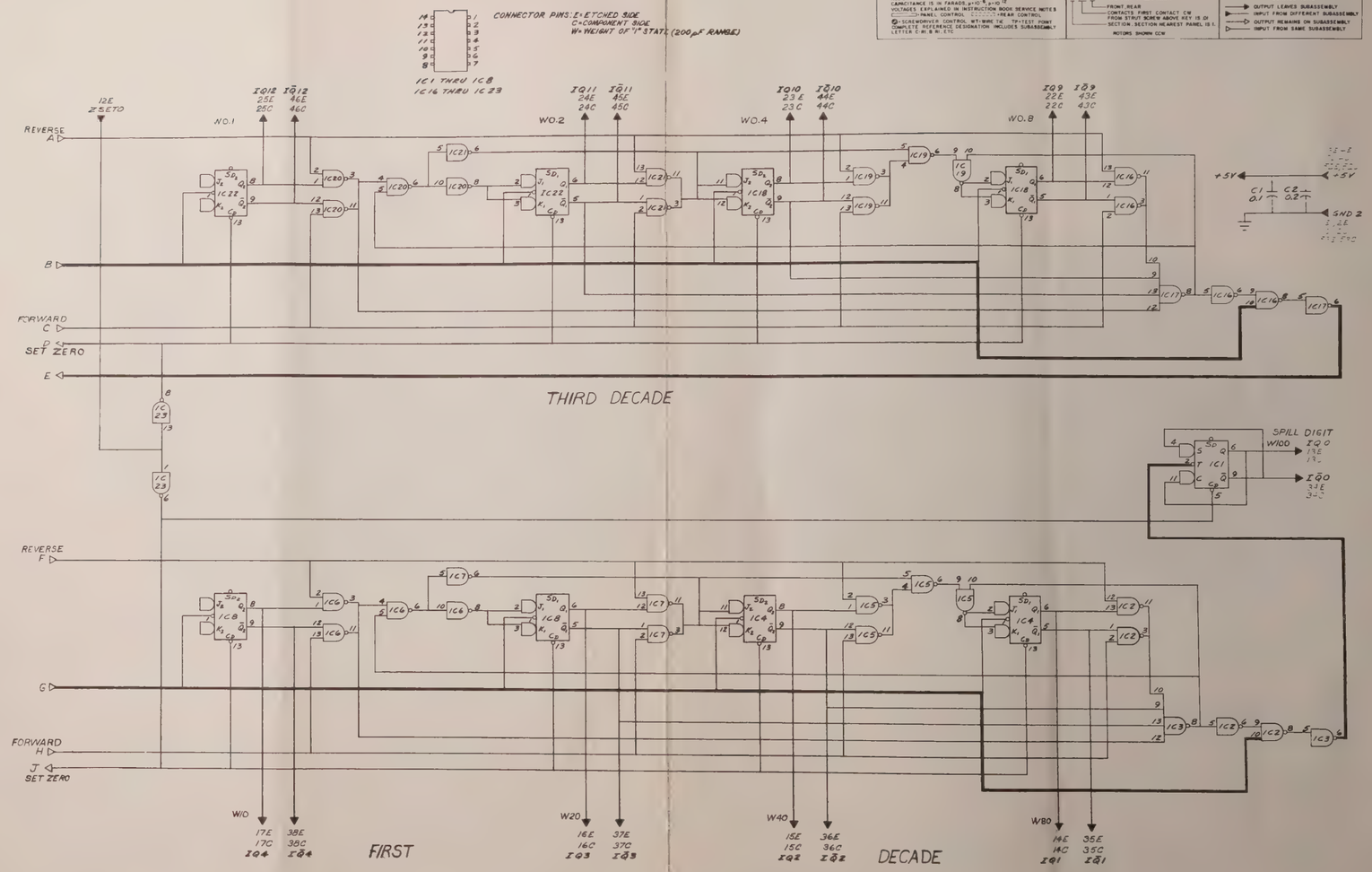


Figure 6-17. C-counter circuit diagram, part 2. I_2

NOTE: This view is the side where parts are mounted; they are shown as areas of wavy lines. Etched circuitry (if any) on this side appears gray; on the other side, black. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

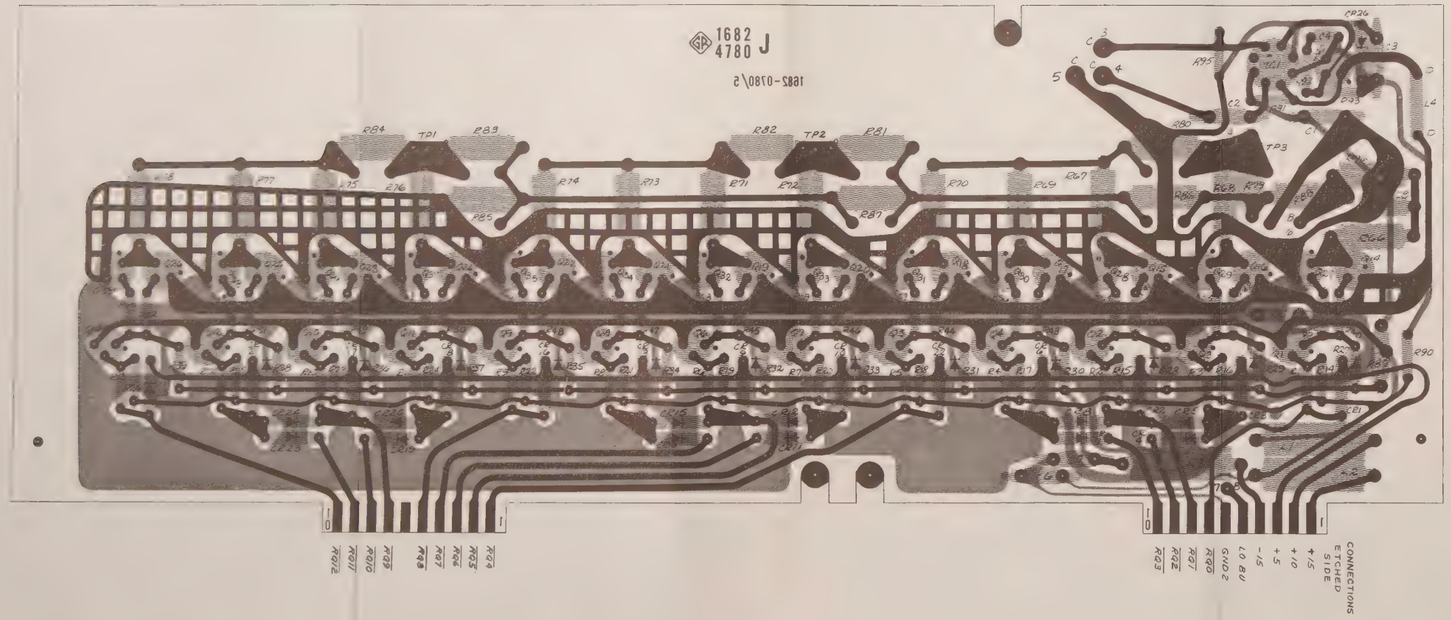


Figure 6-18. J-board assembly, showing etched circuit (P/N 1682-4780).

ELECTRICAL PARTS LIST

J BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
J	G Standards	1682-4780	24655	1682-4780	
CAPACITORS					
C1 thru					
C3	Ceramic, 0.1 µF	4403-4100	80131	CC63, .1 µF +80-20%	5910-974-5699
C4	Ceramic, 680 pF, +80-20%	4404-1689	72982	831, 680 pF +80-20%	
C5 thru					
C7	Ceramic, 0.1 µF	4403-4100	80131	CC63, .1 µF +80-20%	5910-974-5699
DIODES					
CR1 thru					
CR3	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR4 and					
CR5	Type 1N695	6082-1014	24446	1N695	
CR6	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR7 and					
CR8	Type 1N695	6082-1014	24446	1N695	
CR9 and					
CR10	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR11 and					
CR12	Type 1N695	6082-1014	24446	1N695	
CR13	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR14 and					
CR15	Type 1N695	6082-1014	24446	1N695	
CR16 thru					
CR18	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR19 and					
CR20	Type 1N695	6082-1014	24446	1N695	
CR21 and					
CR22	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR23 and					
CR24	Type 1N695	6082-1014	24446	1N695	
CR25	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR26	Type 1N758A	6083-1012	07910	1N758A	
INDUCTORS					
L1 thru					
L3	Choke, Molded, 100 µH, ±10%	4300-3500	99800	2890-42, 100 µH 10%	
L4	Ferrite Bead	5000-1250	02114	56-590-65/4B	
INTEGRATED CIRCUITS					
IC1	Linear	5432-3028	79089	CA3028A	
RESISTORS					
R1	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R2	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R3	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R4 thru					
R13	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R14	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R15	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R16	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ, 5%	5905-686-9992
R17 thru					
R26	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R27 thru					
R31	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R32 thru					
R39	Comp., 15 kΩ, ±5%	6099-3155	75042	BTS, 15 kΩ 5%	5905-681-8818
R40 thru					
R52	Comp., 8.2 kΩ, ±5%	6099-2825	75042	BTS, 8.2 kΩ 5%	
R53 thru					
R65	Comp., 4.3 kΩ, ±5%	6099-2435	75042	BTS, 4.3 kΩ 5%	
R66	Film, 10 kΩ, ±.1%	6190-5665	75042	MEA, 10 kΩ .1%	
R67 thru					
R69	Film, 1 kΩ, ±.1%	6190-2335	75042	MEA, 1 kΩ .1%	
R70	Film, 2 kΩ, ±.1%	6190-3310	75042	MEA, 2 kΩ .1%	
R71 thru					
R73	Film, 1 kΩ, ±.1%	6190-2335	75042	MEA, 1 kΩ .1%	

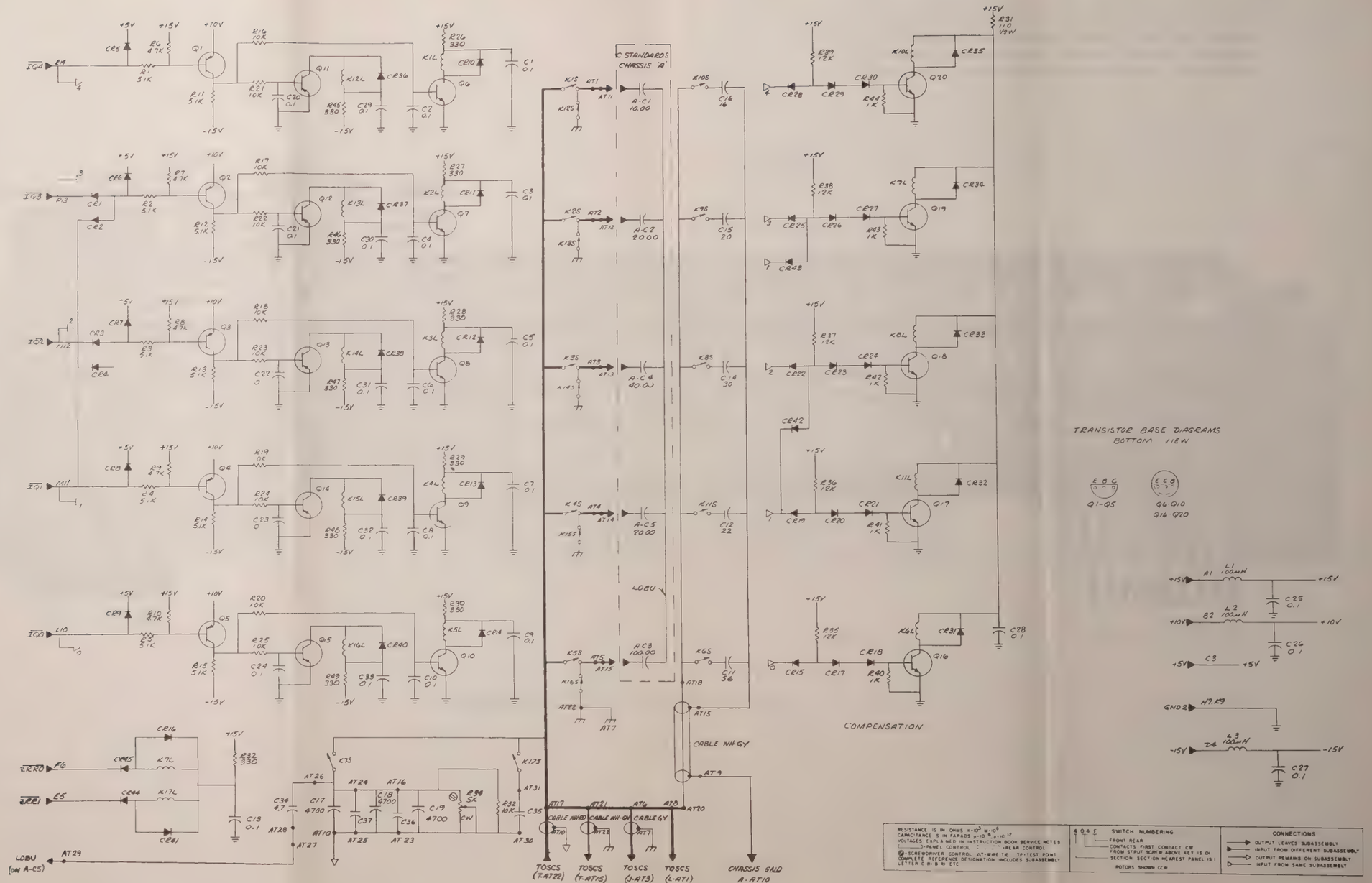


Figure 6-21 (K) →

Figure 6-21. Large-C-standard switching diagram. K

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears gray; on the other side, black. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

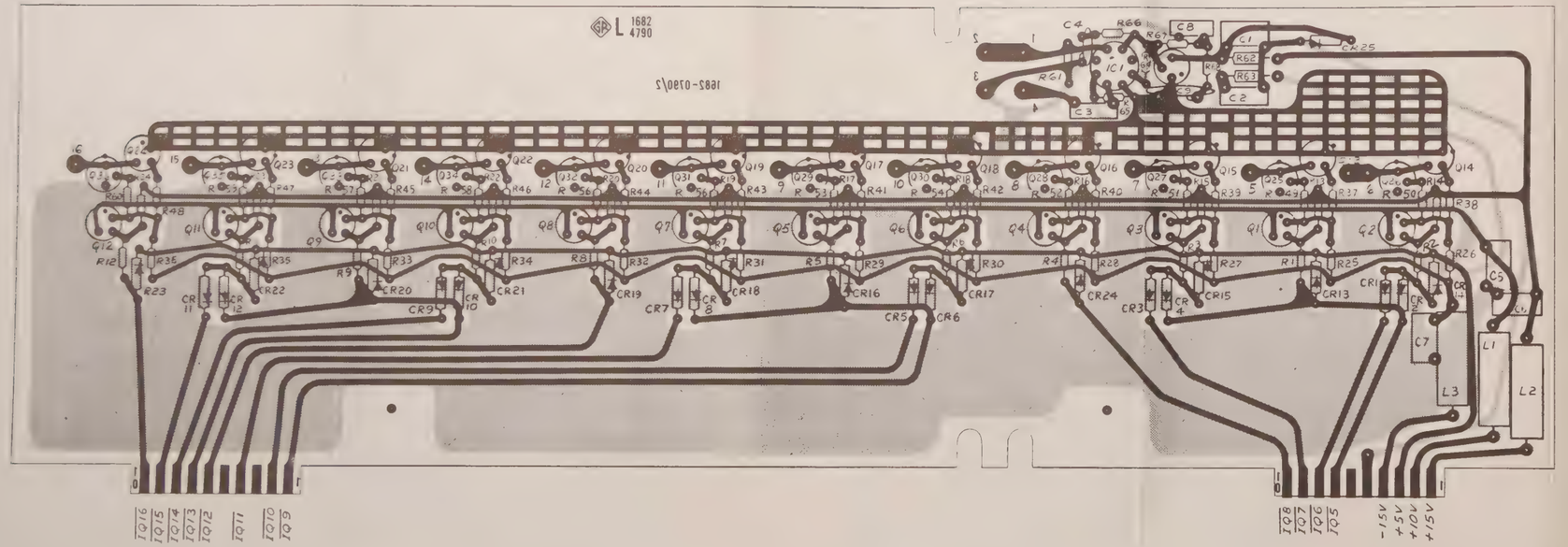


Figure 6-22. L-board assembly, showing etched circuit (P/N 1682-4790).

ELECTRICAL PARTS LIST

L BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
L	Small-C-Standard Switching	1682-4790	24655	1682-4790	
CAPACITORS					
C1 thru					
C3	Ceramic, 0.1 μF	4400-2050	80183	5C13, .1 uF 20%	5910-080-4646
C4	Ceramic, 180 pF	4404-1188	72982	831, 180 pF 10%	
C5 thru					
C7	Ceramic, 0.47 μF	4400-2054	80183	5C13, .47 uF 20%	5910-933-4005
C8	Mica *	4700——			
DIODES					
CR1 thru					
CR12	Type 1N695	6082-1014	24446	1N695	
CR13 thru					
CR24	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR25	Type 1N758A	6083-1012	07910	1N758A	
INDUCTORS					
L1 thru					
L3	Molded choke	4300-3500	99800	2890-42, 100 μH 10%	
INTEGRATED CIRCUITS					
IC1	Linear	5432-3028	79089	CA3028A	
RESISTORS					
R1	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R2	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R3 thru					
R12	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R13	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R14	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R15 thru					
R24	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R25	Comp., 12 kΩ, ±5%	6099-3125	75042	BTS, 12 kΩ 5%	
R26	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R27	Comp., 12 kΩ, ±5%	6099-3125	75042	BTS, 12 kΩ 5%	
R28 thru					
R36	Comp., 22 kΩ, ±5%	6099-3225	75042	BTS, 22 kΩ 5%	5905-687-0002
R37 thru					
R44	Comp., 15 kΩ, ±5%	6099-3155	75042	BTS, 15 kΩ 5%	5905-681-8818
R45 thru					
R48	Comp., 22 kΩ, ±5%	6099-3225	75042	BTS, 22 kΩ 5%	5905-687-0002
R49	Comp., 2.7 kΩ, ±5%	6099-2275	75042	BTS, 2.7 kΩ 5%	
R50	Comp., 1.5 kΩ, ±5%	6099-2155	75042	BTS, 1.5 kΩ 5%	
R51	Comp., 2.7 kΩ, ±5%	6099-2275	75042	BTS, 2.7 kΩ 5%	
R52 thru					
R60	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R61	Comp., 68 kΩ, ±5%	6099-3685	75042	BTS, 68 kΩ, 5%	5905-681-8853
R62	Comp., 150 Ω ±5%	6099-1155	75042	BTS, 150 Ω 5%	5905-683-2243
R63	Comp., 300 Ω, ±5%	6100-1305	01121	RC20GF301J	5905-279-5481
R64	Comp., 1.1 kΩ, ±5%	6099-2115	75042	BTS, 1.1 kΩ 5%	
R65	Comp., 330 Ω, ±5%	6099-1335	75042	BTS, 330 Ω 5%	5905-686-3369
R66	Comp., 68 Ω ±5%	6099-0685	75042	BTS, 68 Ω 5%	
R67 and					
R68	Comp.*	6099——			
TRANSISTORS					
Q1 thru					
Q12	Type 2N4125	8210-1125	04713	2N4125	
Q13 thru					
Q24	—	8210-1174	24655	8210-1174	
Q25 thru					
Q36	Type GA2390	8210-1081	96214	GA2390	
Q37	Type 2N3905	8210-1114	04713	2N3905	

*Value determined as required.

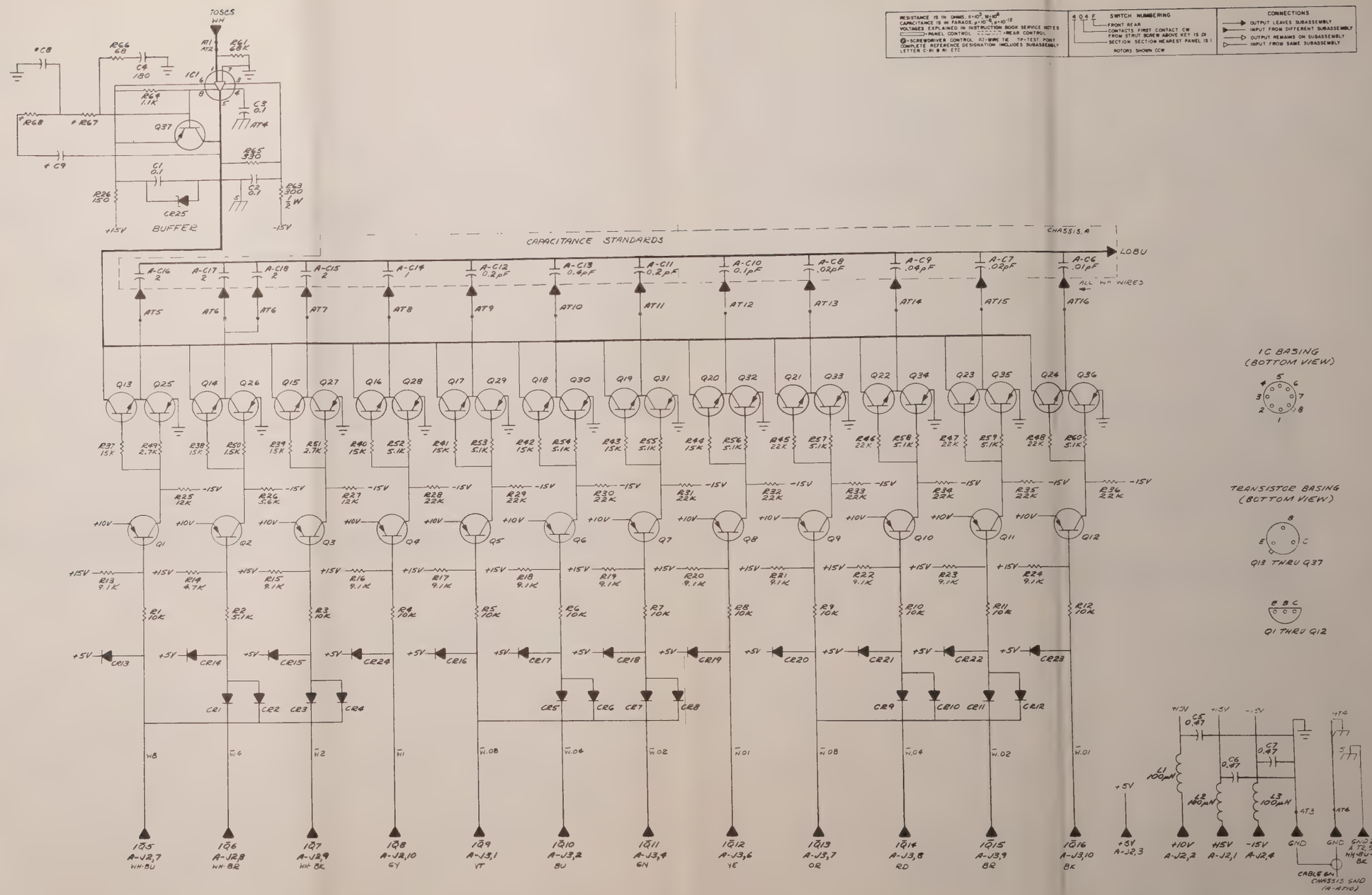


Figure 6-23 (L) →

Figure 6-23. Small-C-standard switching diagram. L

NOTE: This view is the side where parts are mounted; they are shown as areas of wavy lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

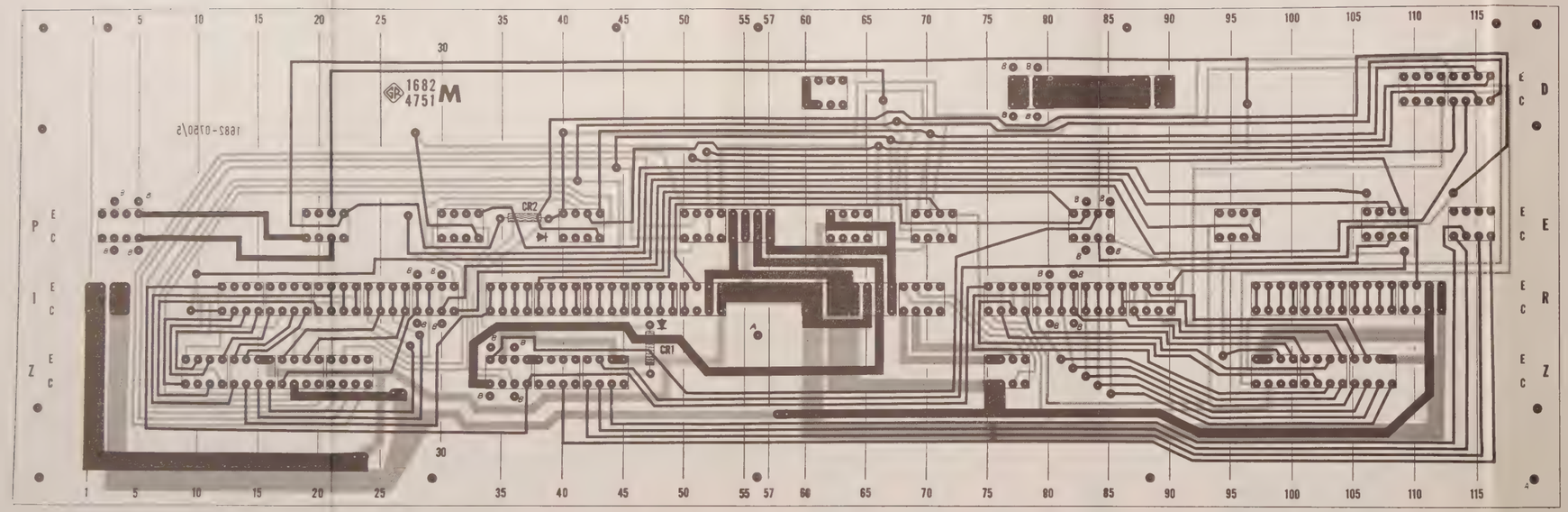


Figure 6-24. Mother-board etched-circuit layout (P/N 1682-4751).

*Note: This board is replaceable only by the General Radio Service Department.

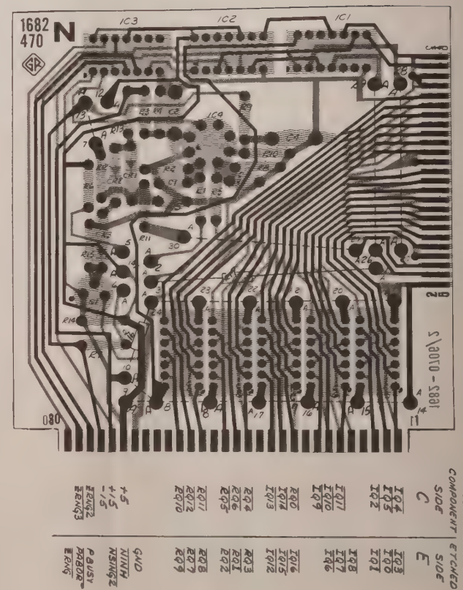


Figure 6-25. N-board assembly, showing etched circuit (P/N 1682-4706 or 1682-4707).

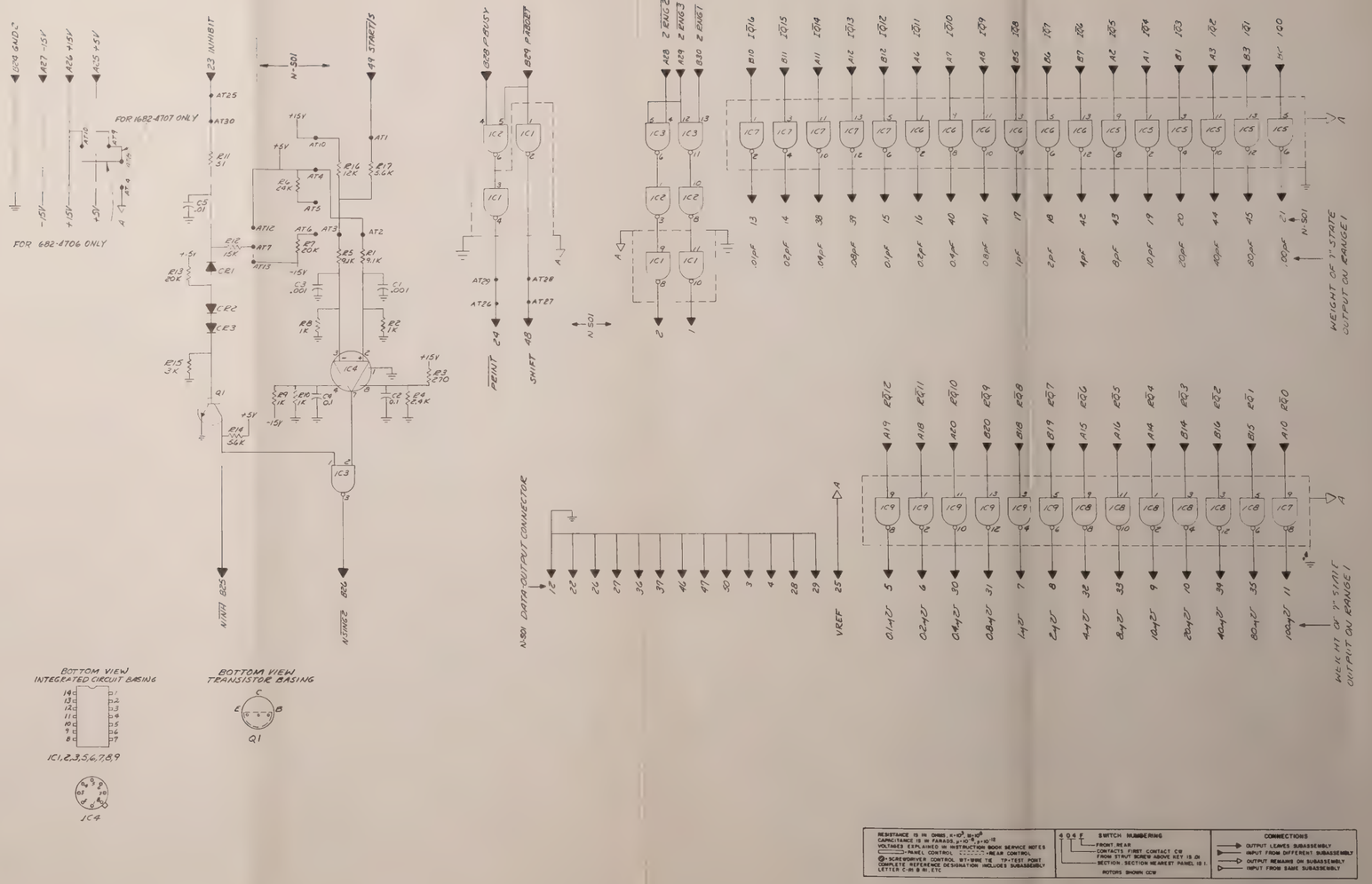
ELECTRICAL PARTS LIST

N BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
	COMPLETE BOARD				
N	Data-Output Interface:				
	Low-Level Outputs (Option 5A)	1682-4707	24655	1682-4707	
	High-Level Outputs (Option 5B)	1682-4706	24655	1682-4706	
	CAPACITORS				
C1	Ceramic, .001 μF, +80-20%	4404-2109	72982	831, .001 μF +80-20%	5910-075-9607
C2	Ceramic, .1 μF, +80-20%	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C3	Ceramic, .001 μF, +80-20%	4404-2109	72982	831, .001 μF +80-20%	5910-075-9607
C4	Ceramic, .1 μF, +80-20%	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C5	Ceramic, .01 μF +80-20%	4401-3100	80131	CC61, .01 μF +80-20%	5910-974-5697
	DIODES				
CR1 thru CR3	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
	INTEGRATED CIRCUITS				
IC1*	Low-Level digital (Option 5A)	5431-9608	07263	TTL-9901659	
IC1*	High-Level digital (Option 5B)	5431-9112	07263	DTμL-9112	
IC2 and IC3	Digital	5431-9462	96214	SN15846N	
IC4	Linear	5432-7101	07263	U5B771039X	
IC5 thru IC9*	Low-Level digital (Option 5A)	5431-9608	07263	TTL-9901659	
IC5 thru IC9*	High-Level digital (Option 5B)	5431-9112	07263	DTμL-9112	
	RESISTORS				
R1	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ ±5%	5905-279-4619
R2	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R3	Comp., 270 Ω, ±5%	6099-1275	75042	BTS, 270 Ω 5%	
R4	Comp., 2.4 kΩ, ±5%	6099-2245	75042	BTS, 2.4 kΩ 5%	5905-683-7724
R5	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R6	Comp., 24 kΩ, ±5%	6099-3245	75042	BTS, 24 kΩ 5%	
R7 R8 thru	Comp., 20 kΩ, ±5%	6099-3205	75042	BTS, 20 kΩ 5%	5905-686-3368
R10	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R11	Comp., 51 Ω, ±5%	6099-0515	75042	BTS, 51 Ω 5%	
R12	Comp., 15 kΩ, ±5%	5099-3155	75042	BTS, 15 kΩ 5%	5905-681-8818
R13	Comp., 20 kΩ, ±5%	6099-3205	75042	BTS, 20 kΩ 5%	5905-686-3368
R14	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R15	Comp., 3 kΩ, ±5%	6099-2305	75042	BTS, 3 kΩ 5%	5905-682-4097
R16	Comp., 12 kΩ, ±5%	6099-3125	75042	BTS, 12 kΩ 5%	
R17	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
	TRANSISTORS				
Q1	Type 2N3414	8210-1047	24446	2N3414	5961-989-2749

*Note There is a dual listing of IC1 and IC5 through 9. Refer to the Options.

Figure 6-26 (N) →



RESISTANCE IS IN OHMS, K=10^3, M=10^6
CAPACITANCE IS IN FARADS, μ=10^{-6}, p=10^{-12}
VOLTAGES EXPLAINED IN INSTRUCTION BOOK SERVICE NOTES
——— PANEL CONTROL, - - - - REAR CONTROL
Ø= SCREWDRIVER CONTROL, BT=TIME TE TP=TEST POINT
COMPLETE REFERENCE DESIGNATION INCLUDES SUBASSEMBLY LETTER C-IN B-IN, ETC

405F SWITCH NUMBERING
FRONT REAR
CONTACTS FIRST CONTACT CW FROM STRUT SCREW ABOVE KEY IS 01
SECTION SECTION NEAREST PANEL IS 1
ROTORS SHOWN CCW

CONNECTIONS
OUTPUT LEAVES SUBASSEMBLY
INPUT FROM DIFFERENT SUBASSEMBLY
OUTPUT REMAINS ON SUBASSEMBLY
INPUT FROM SAME SUBASSEMBLY

Figure 6-26. Data-output interface diagram. N

ELECTRICAL PARTS LIST

O BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
O		1682-4775	24655	1682-4775	
CAPACITORS					
C1	Ceramic, 0.1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C2	Porcelain	4391-1600	95275	V404C, 1000 pF 5%	
C3	Ceramic, 0.1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C5 thru C7	Ceramic, 0.1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C10 thru C12	Ceramic, 0.1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C14 thru C16	Ceramic, 0.1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C17	Ceramic, 470 pF	4404-1475	72982	831, 470 pF 5%	
CRYSTAL					
Y1	Precision Resonator, 1 MHz	1682-0400	24655	1682-0400	
DIODES					
CR1	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR4 thru CR10	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
INDUCTORS					
L1 and L2	Molded choke, 100 μH	4300-3500	99800	2890-42, 100 μH 10%	
RELAYS					
K1S thru K3S	Reed switch	6090-0800	30874	76586S	
K1L thru K3L	Reed coil	6090-1130	71707	XU-8242-P	
RESISTORS					
R1	Comp., 180 Ω, ±5%	6099-1185	75042	BTS, 180 Ω 5%	5905-682-4107
R2	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R3	Comp., 6.8 kΩ, ±5%	6099-2685	75042	BTS, 6.8 kΩ 5%	5905-686-9997
R4	Comp., 2.2 kΩ, ±5%	6099-2225	75042	BTS, 2.2 kΩ 5%	5905-723-5251
R5	Comp., 110 Ω, ±5%	6099-1115	75042	BTS, 110 Ω 5%	
R6	Comp., 390 Ω, ±5%	6099-1395	75042	BTS, 390 Ω 5%	
R7	Comp., 470 Ω, ±5%	6099-1475	75042	BTS, 470 Ω 5%	5905-683-2242
R8	Comp., 1.8 kΩ, ±5%	6099-2185	75042	BTS, 1.8 kΩ 5%	5905-688-3738
R9	Comp., 2.2 kΩ, ±5%	6099-2225	75042	BTS, 2.2 kΩ 5%	5905-723-5251
R10	Comp., 180 Ω, ±5%	6099-1185	75042	BTS, 180 Ω 5%	5905-682-4107
R11 and R12	Comp., 330 Ω, ±5%	6100-1335	01121	RC20GF331J	5905-192-3971
R16	Comp., 470 Ω, ±5%	6099-1475	75042	BTS, 470 Ω 5%	5905-683-2242
R17	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R18	Comp., 75 Ω, ±5%	6099-0755	75042	BTS, 75 Ω 5%	
R19	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R20	Comp., 220 Ω, ±5%	6099-1225	75042	BTS, 220 Ω 5%	5905-683-2240
R21	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R22 and R23	Comp., 51 Ω, ±5%	6099-0515	75042	BTS, 51 Ω 5%	
R24	Comp., 470 Ω, ±5%	6110-1475	01121	RC32GF471J	5905-299-2051
R25	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
TRANSFORMERS					
T1	Transformer	1682-2510	24655	1682-2510	
T2	Transformer	1682-2530	24655	1682-2530	
TRANSISTORS					
Q1 and Q2	Type 2N2369	8210-1052	96214	2N2369	
Q3	Type 2N2904	8210-1074	07263	2N2904	
Q4	Type 2N2218	8210-1028	96214	2N2218	5960-059-4464

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

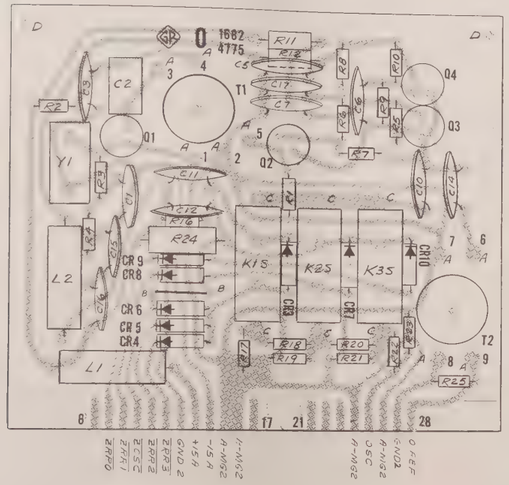
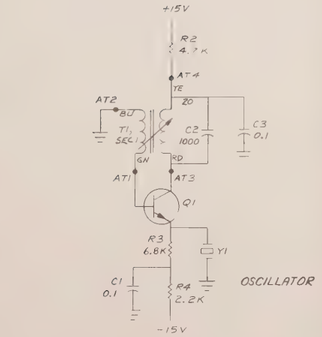
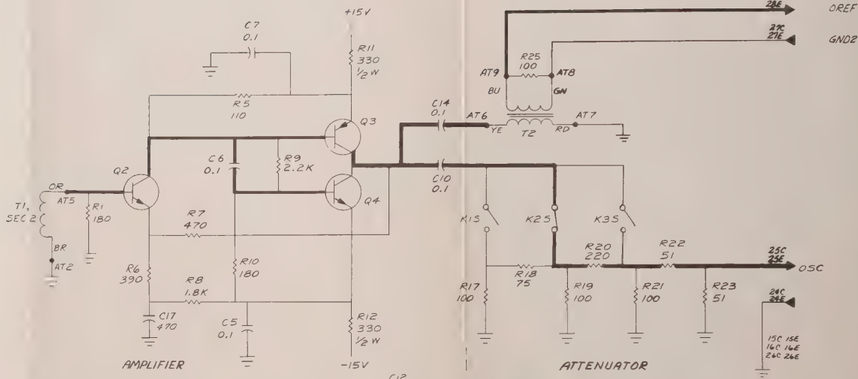
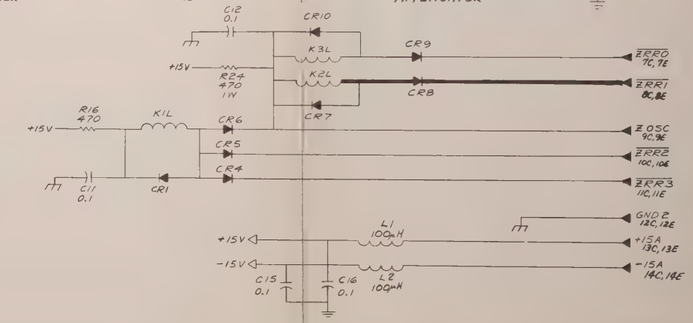
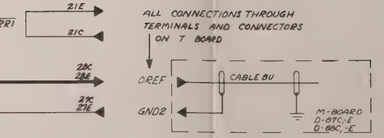


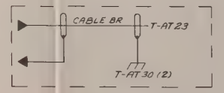
Figure 6-27. O-board assembly, showing etched circuit (P/N 1682-4775).











RELAY CONTACTS ARE SHOWN IN RANGE 1 (200 pF, POSITION

RESISTANCE IS IN OHMS, K=10³, M=10⁶
CAPACITANCE IS IN FARADS, μ=10⁻⁶, p=10⁻¹²
VOLTAGES EXPLAINED IN INSTRUCTION BOOK SERVICE NOTES
PANEL CONTROL
REAR CONTROL
SCREWDRIVER CONTROL
POTENTIOMETER
TP-TEST POINT
COMPLETE REFERENCE DESIGNATION INCLUDES SUBASSEMBLY LETTER C-M1 B-W1, ETC
4 0 4 E
SWITCH NUMBERING
FRONT REAR
CONTACTS FIRST CONTACT CW FROM STRUT SCREW ABOVE KEY IS OR SECTION SECTION NEAREST PANEL IS 1
ROTORS SHOWN CCW
CONNECTIONS
OUTPUT LEAVES SUBASSEMBLY
INPUT FROM DIFFERENT SUBASSEMBLY
OUTPUT REMAINS ON SUBASSEMBLY
INPUT FROM SAME SUBASSEMBLY

Figure 6-28. Oscillator diagram. O

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

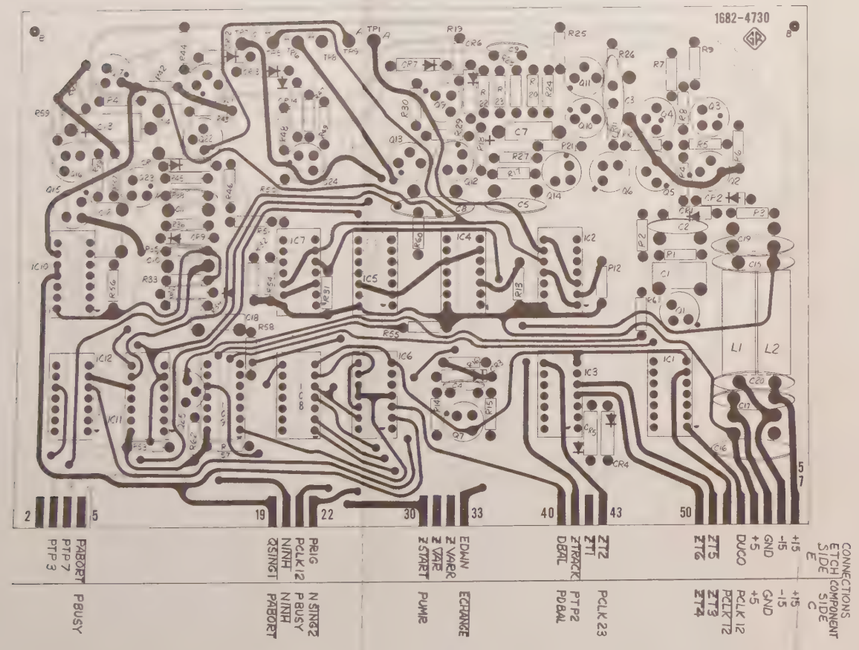


Figure 6-29. P-board assembly, showing etched circuit (P/N 1682-4730).

ELECTRICAL PARTS LIST

P BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
P	Digital Control	1682-4730	24655	1682-4730	
CAPACITORS					
C1	Ceramic, 0.22 µF	4400-2052	80183	5C13, .22 µF 20%	5910-974-5694
C2	Ceramic, 2200 pF	4406-2225	72982	811, 2200 pF 10%	5910-899-0668
C3	Ceramic, 0.1 µF	4400-2050	80183	5C13, .1 µF ±20%	5910-080-4646
C4	Ceramic, 180 pF	4404-1188	72982	831, 180 pF ±10%	
C5	Ceramic, .01 µF	4406-3109	72982	811, .01 µF +80-20%	5910-777-5779
C7	Tantalum, 2.2 µF	4450-4500	56289	150D225X0020A2	5910-976-4604
C8	Ceramic, 0.1 µF	4400-2050	80183	5C13, .1 µF ±20%	5910-080-4646
C9	Ceramic, 100 pF	4404-1109	72982	831, 100 pF +80-20%	
C10 and C11	Ceramic, .02 µF	4402-3200	01121	35-203W	5910-974-5698
C12	Ceramic, 1 µF	4400-2070	80183	5C13, 1 µF 20%	5910-083-6445
C13	Tantalum, 15 µF	4450-5200	56289	150D156X0020B2	5910-855-6335
C14	Ceramic, 2.2 µF	4400-2080	80183	5C13, 2.2 µF 20%	
C15 thru C20	Ceramic, 0.1 µF	4400-2050	80183	5C13, .1 µF ±20%	5910-080-4646
C21	Ceramic, .001 µF	4404-2109	72982	831, .001 µF +80-20%	5910-075-9607
DIODES					
CR1 thru CR9	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR11 thru CR14	Type 1N3604	6082-1001			
CR15	Type 1N995	6082-1002	80368	1N995	5961-893-6762
INDUCTORS					
L1 and L2	Molded choke	4300-3500	99800	2890-42, 100 µH 10%	
INTEGRATED CIRCUITS					
IC1	Digital	5431-9322	96214	SN15832N	
IC2	Digital	5431-9462	96214	SN15846N	
IC3	Digital	5431-9322	96214	SN15832N	
IC4	Digital	5431-9372	96214	SN15837N	
IC5	Digital	5431-9322	96214	SN15832N	
IC6	Digital	5431-9372	96214	SN15837N	
IC7	Digital	5431-9492	96214	SN15849N	
IC8 and IC9	Digital	5431-9462	96214	SN15846N	
IC10	Digital	5431-9302	96214	SN15830N	
IC11	Digital	5431-9442	96214	SN15844N	
IC12	Digital	5431-9462	96214	SN15846N	
		5431-9302	96214	SN15830N	
		5431-9452	96214	SN15845N	
RESISTORS					
R1	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R2	Comp., 130 Ω, ±5%	6099-1135	75042	BTS, 130 Ω 5%	5905-807-0269
R3	Comp., 3 kΩ, ±5%	6099-2305	75042	BTS, 3 kΩ 5%	5905-682-4097
R4	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R5	Comp., 2 kΩ, ±5%	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370
R6	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R7	Comp., 3 kΩ, ±5%	6099-2305	75042	BTS, 3 kΩ 5%	5905-682-4097
R8	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R9	Comp., 10 Ω, ±5%	6099-0105	75042	BTS, 10 Ω 5%	5905-809-8596
R10	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R11	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R12 and R13	Comp., 560 Ω, ±5%	6099-1565	75042	BTS, 560 Ω 5%	
R14	Comp., 1.5 kΩ, ±5%	6099-2155	75042	BTS, 1.5 kΩ 5%	
R15	Comp., 7.5 kΩ, ±5%	6099-2755	75042	BTS, 7.5 kΩ 5%	
R16	Comp., 560 Ω, ±5%	6099-1565	75042	BTS, 560 Ω 5%	
R17	Comp., 510 Ω, ±5%	6099-1515	75042	BTS, 510 Ω 5%	5905-801-8272
R18	Comp., 51 Ω, ±5%	6099-0515	75042	BTS, 51 Ω 5%	
R19	Comp., 15 kΩ, ±5%	6099-3155	75042	BTS, 15 kΩ 5%	5905-681-8818
R20	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422

ELECTRICAL PARTS LIST

P BOARD (Cont'd)

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
RESISTORS (Cont)					
R21 and R22	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R23	Comp., 20 kΩ, ±5%	6099-3205	75042	BTS, 20 kΩ 5%	5905-686-3368
R24	Comp., 3 kΩ, ±5%	6099-2305	75042	BTS, 3 kΩ 5%	5905-682-4097
R25	Comp., 10 Ω, ±5%	6099-0105	75042	BTS, 10 Ω 5%	5905-809-8596
R26	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R27 and R28	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R29	Comp., 5.1 kΩ, ±5%	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R30	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R31	Comp., 560 Ω, ±5%	6099-1565	75042	BTS, 560 Ω 5%	
R32	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R33	Comp., 3.9 kΩ, ±5%	6099-2395	75042	BTS, 3.9 kΩ 5%	
R34	Comp., 16 kΩ, ±5%	6099-3165	75042	BTS, 16 kΩ 5%	
R35	Comp., 3.9 kΩ, ±5%	6099-2395	75042	BTS, 3.9 kΩ 5%	
R36	Comp., 16 kΩ, ±5%	6099-3165	75042	BTS, 16 kΩ 5%	
R37	Comp., 51 kΩ, ±5%	6099-3515	75042	BTS, 51 kΩ 5%	5905-682-4103
R38	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R39	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R40	Comp., 150 kΩ, ±5%	6099-4155	75042	BTS, 150 kΩ 5%	5905-686-9995
R41	Comp., 150 Ω, ±5%	6099-1155	75042	BTS, 150 Ω 5%	5905-683-2243
R42	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R43	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R44	Comp., 100 kΩ, ±5%	6099-4105	75042	BTS, 100 kΩ 5%	5905-686-3129
R45 and R46	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ ±5%	5905-691-0195
R47	Comp., 6.2 kΩ, ±5%	6099-2625	75042	BTS, 6.2 kΩ 5%	5905-682-4100
R48	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R49	Comp., 12 kΩ, ±5%	6099-3125	75042	BTS, 12 kΩ 5%	
R50	Comp., 2 kΩ, ±5%	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370
R51	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R53 thru R55	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R56	Comp., 510 Ω, ±5%	6099-1515	75042	BTS, 510 Ω ±5%	5905-801-8272
R57	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R58	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R59	Comp., 330 Ω, ±5%	6099-1335	75042	BTS, 330 Ω 5%	
R60 and R61	Comp., 510 Ω, ±5%	6099-1515	75042	BTS, 510 Ω 5%	5905-801-8272
R62	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R63	Comp., 1 kΩ ±5%	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6422
TRANSISTORS					
Q1	Type 2N3414	8210-1047	24446	2N3414	5961-989-2749
Q2	Type 2N4125	8210-1125	04713	2N4125	
Q3 and Q4	Type 2N3391A	8210-1092	24454	2N3391A	
Q5	Type 2N4125	8210-1125	04713	2N4125	
Q6 and Q7	Type 2N3646	8210-1119	07263	2N3646	5961-964-5753
Q9	Type 2N4125	8210-1125	04713	2N4125	
Q10 and Q11	Type 2N3391A	8210-1092	24454	2N3391A	
Q12	Type 2N4125	8210-1125	04713	2N4125	
Q13	Type 2N3646	8210-1119	07263	2N3646	5961-964-5753
Q14 and Q15	Type 2N3414	8210-1047	24446	2N3414	5961-989-2749
Q16	Type 2N1671B	8210-1026	24454	2N1671B	
Q17	Type 2N3391A	8210-1092	24454	2N3391A	
Q21 and Q22	Type 2N3414	8210-1047	24446	2N3414	5961-989-2749
Q23	Type 2N3646	8210-1119	07263	2N3646	5961-964-5753
Q24	Type 2N4125	8210-1125	04713	2N4125	

Figure 6-30 (P) →

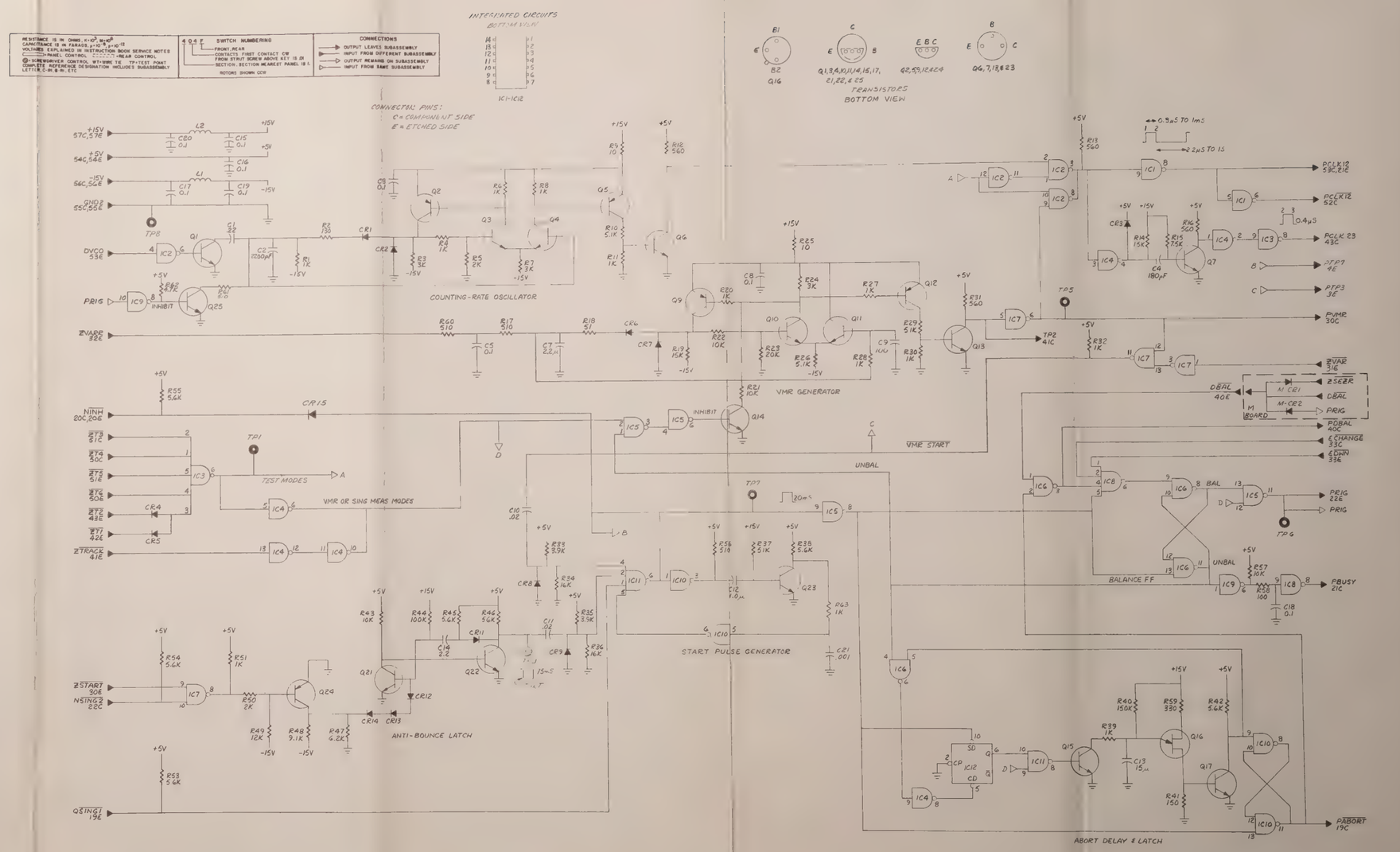


Figure 6-30. Digital control circuit diagram. P

ELECTRICAL PARTS LIST

Q BOARD

Ref Des	Description	GR Part No	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
Q	Auxiliary-Instruments Interface	1682-4715	24655	1682-4715	
CAPACITORS					
C1 thru C3	Ceramic, .01 µF	4401-3100	80131	CC61, .01 µF +80-20%	5910-974-5697
C5 thru C14	Ceramic, .01 µF	4401-3100	80131	CC61, .01 µF +80-20%	5910-974-5697
C15	Ceramic, .1 µF	4403-4100	80131	CC63, .1 µF +80-20%	5910-974-5699
C17	Ceramic, .01 µF	4401-3100	80131	CC61, .01 µF +80-20%	5910-974-5697
INTEGRATED CIRCUITS					
IC1 thru IC3	Digital	5431-9362	96214	SN15836N	
IC4	Digital	5431-9452	96214	SN15845N	
IC5	Digital	5431-9362	96214	SN15836N	
IC6 thru IC8	Digital	5431-9462	96214	SN15846N	
RESISTORS					
R1 thru R3	Comp., 51 Ω, ±5%	6099-0515	75042	BTS, 51 Ω 5%	
R5 thru R13	Comp., 51 Ω, ±5%	6099-0515	75042	BTS, 51 Ω 5%	
R14 thru R16	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R18 thru R27	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R28	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R29	Comp., 51 Ω, ±5%	6099-0515	75042	BTS, 51 Ω 5%	
R30	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R32	Comp., 51 Ω, ±5%	6099-0515	75042	BTS, 51 Ω 5%	

NOTE: This view is the side where parts are mounted; they are shown as areas of wavy lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

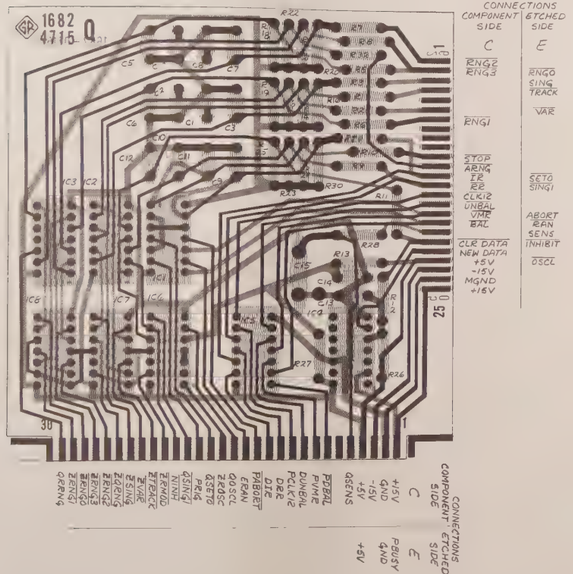


Figure 6-31. Q-board assembly, showing etched circuit (P/N 1682-4715).

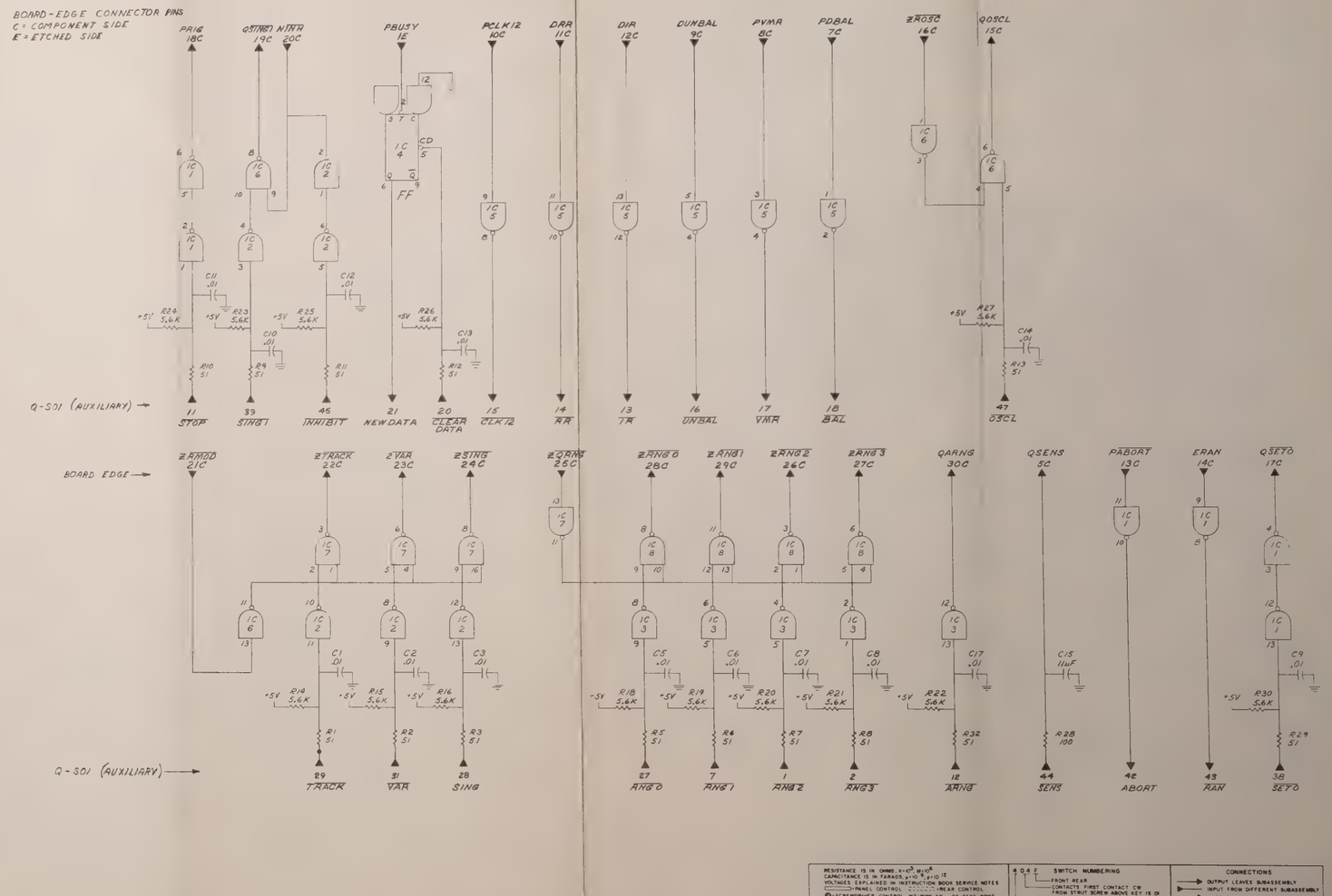


Figure 6-32. Auxiliary instruments' interface diagram. Q

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

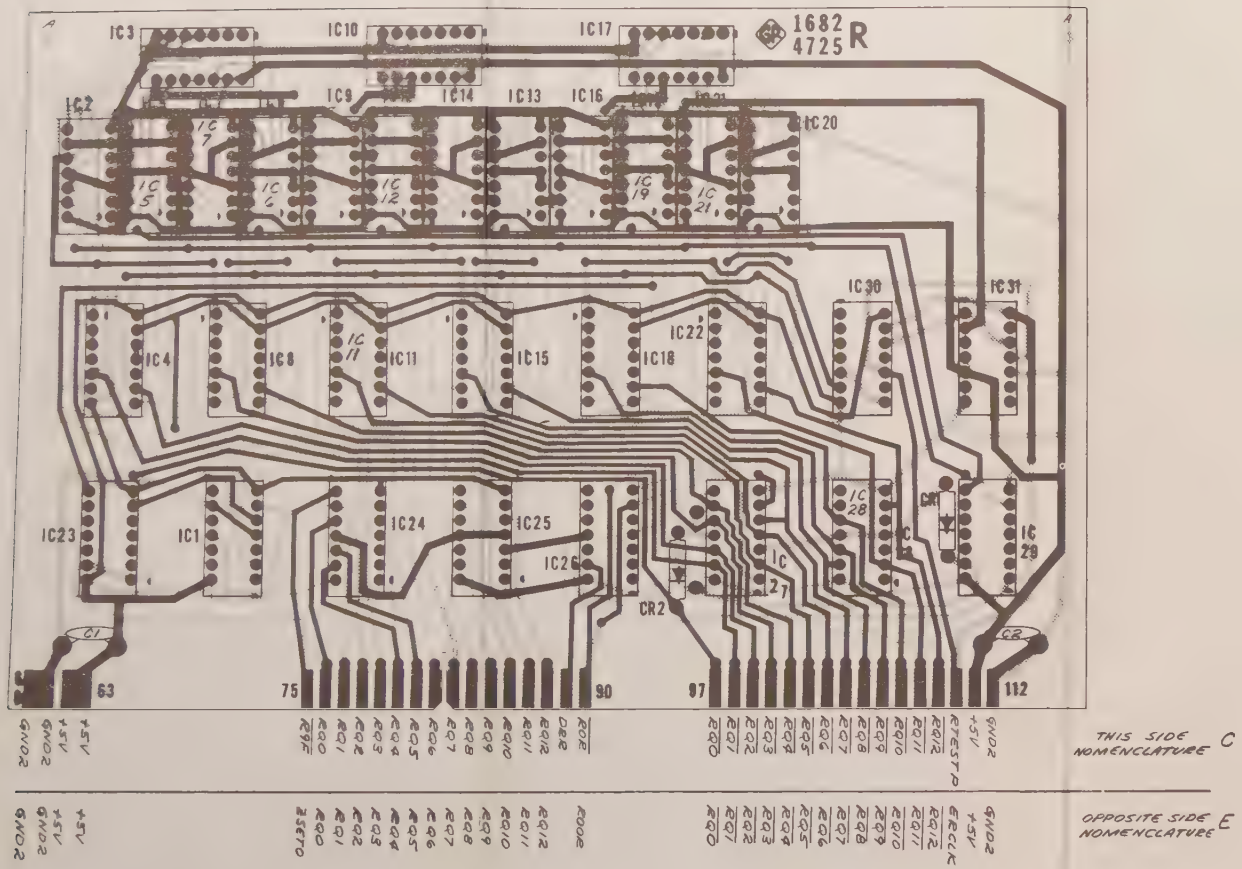


Figure 6-33. R-board assembly, showing etched circuit (P/N 1682-4725).

ELECTRICAL PARTS LIST

R BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
R	G Counter	1682-4725	24655	1682-4725	
CAPACITORS					
C1 and C2	Ceramic, 0.1 μF	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
DIODES					
CR1 and CR2	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
INTEGRATED CIRCUITS					
IC1	Digital	5431-9452	96214	SN15845N	
IC2	Digital	5431-9492	96214	SN15849N	
IC3	Digital	5431-9322	96214	SN15832N	
IC4	Digital	5431-9099	96214	SN158099N	
IC5 thru IC7	Digital	5431-9462	96214	SN15846N	
IC8	Digital	5431-9099	96214	SN158099N	
IC9	Digital	5431-9492	96214	SN15849N	
IC10	Digital	5431-9322	96214	SN15832N	
IC11	Digital	5431-9099	96214	SN158099N	
IC12 thru IC14	Digital	5431-9462	96214	SN15846N	
IC15	Digital	5431-9099	96214	SN158099N	
IC16	Digital	5431-9492	96214	SN15849N	
IC17	Digital	5431-9322	96214	SN15832N	
IC18	Digital	5431-9099	96214	SN158099N	
IC19 thru IC21	Digital	5431-9462	96214	SN15846N	
IC22	Digital	5431-9099	96214	SN158099N	
IC23 and IC24	Digital	5431-9322	96214	SN15832N	
IC25	Digital	5431-9332	96214	SN15833N	
IC26	Digital	5431-9492	96214	SN15849N	
IC27	Digital	5431-9322	96214	SN15832N	
IC28	Digital	5431-9332	96214	SN15833N	
IC29 and IC30	Digital	5431-9322	96214	SN15832N	
IC31	Digital	5431-8190	96214	SN7490N	

Figure 6-34 (R) →

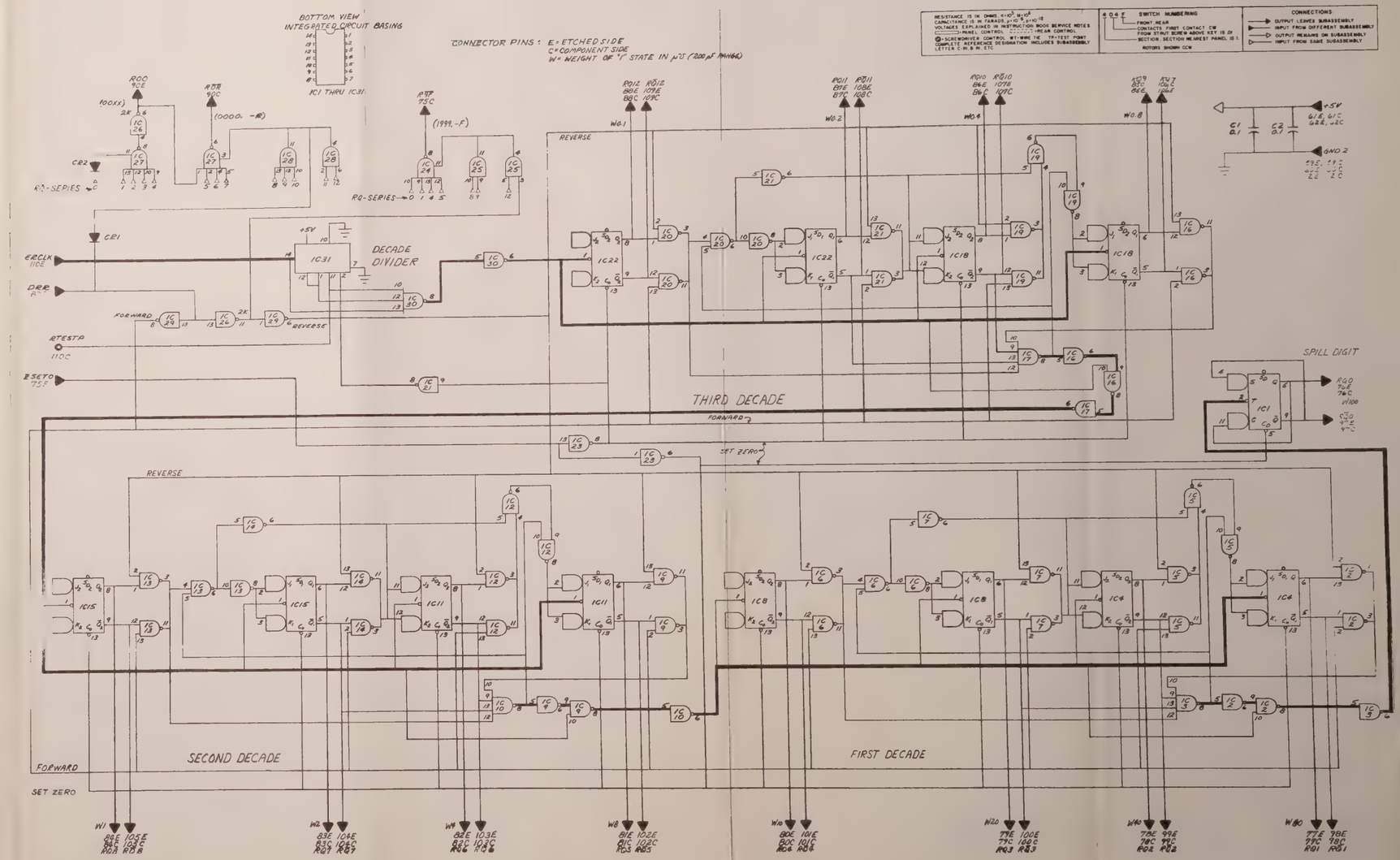


Figure 6-34. G-counter circuit diagram. R

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears gray; on the other side, black. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

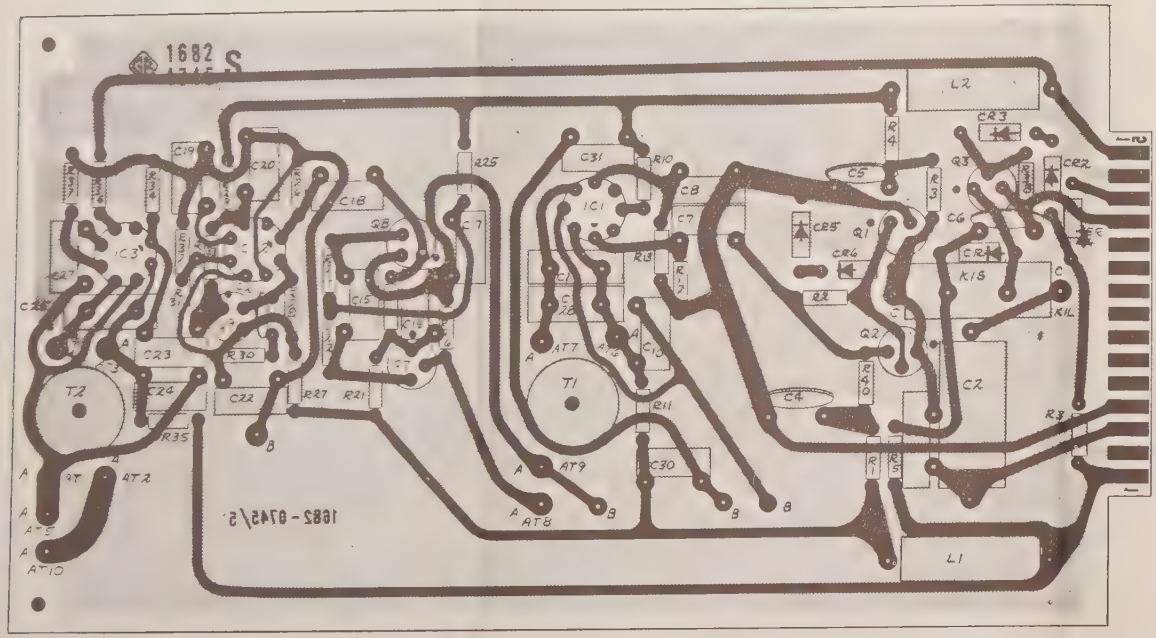


Figure 6-35. S-board assembly, showing etched circuit (P/N 1682-4745).

ELECTRICAL PARTS LIST

S BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
COMPLETE BOARD					
S	Preamplifier	1682-4745	24655	1682-4745	
CAPACITORS					
C1	Mica, 0.787 pF ±1%	4710-0787	14655	22A, .787 pF 1%	
C2	Mica, 1000 pF	4680-3200	81349	CM20D102J	5910-636-2134
C3	Mica, .001 µF ±1%	4710-0100	14655	22A, .001 µF 1%	5910-068-0840
C4 thru C6	Ceramic, 0.1 µF	4403-4100	80131	CC63, .1 µF +80-20%	5910-974-5699
C7,C8	Ceramic, .22 µF	4400-2052	80183	5C13, .22 µF 20%	5910-974-5694
C10	Ceramic, .47 µF	4400-2054	80183	5C13, .47 µF 20%	5910-933-4005
C15	Ceramic, .22 µF	1400-2052	80183	5C13, .22 µF 20%	5910-974-5694
C16 thru C20	Ceramic, .47 µF	4400-2054	80183	5C13, .47 µF 20%	5910-933-4005
C21	Ceramic, .001 µF	4404-2109	72982	831, .001 µF +80-20%	5910-075-9607
C22 thru C24	Ceramic, .47 µF	4400-2054	80183	5C13, .47 µF 20%	5910-933-4005
C25	Mica, .001 µF ±1%	4710-0100	14655	22A, .001 µF 1%	5910-068-0840
C27	Ceramic, .47 µF	4400-2054	80183	5C13, .47 µF 20%	5910-933-4005
C28	Mica, 965 pF, ±0.5%	4710-1965	14655	22A, 965 pF .5%	
C30,C31	Ceramic, .47 µF	4400-2054	80183	5C13, .47 µF 20%	5910-933-4005
DIODES					
CR1 thru CR4	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR5,CR6	Type 1N645	6082-1016	24446	1N645	5961-087-6047
INDUCTORS					
L1,L2	Molded Choke, 100 µH	4300-3500	99800	2890-42, 100 µH 10%	
INTEGRATED CIRCUITS					
IC1 thru IC3	Linear	5432-3028	79089	CA3028A	
RELAYS					
K1L	Reed Coil	6090-1130	71707	XU-8242-P	
K1S	Reed Switch	6090-0800	30874	76586S	
RESISTORS					
R1	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R2	Comp., 680 Ω, ±5%	6099-1685	75042	BTS, 680 Ω 5%	
R3	Comp., 3.9 kΩ, ±5%	6099-2395	75042	BTS, 3.9 kΩ 5%	
R4	Comp., 820 Ω, ±5%	6099-1825	75042	BTS, 820 Ω 5%	
R5	Comp., 470 Ω, ±5%	6099-1475	75042	BTS, 470 Ω 5%	5905-683-2242
R10	Comp., 1.8 kΩ ±5%	6099-2185	75042	BTS, 1.8 kΩ ±5%	5905-688-3738
R11	Comp., 2.2 kΩ, ±5%	6099-2225	75042	BTS, 2.2 kΩ 5%	5905-723-5251
R12 and R13	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R20	Comp., 300 Ω, ±5%	6099-1305	75042	BTS, 300 Ω 5%	5905-279-5481
R21	Comp., 2.2 kΩ, ±5%	6099-2225	75042	BTS, 2.2 kΩ 5%	5905-723-5251
R22	Comp., 1.8 kΩ ±5%	6099-2185	75042	BTS, 1.8 kΩ ±5%	5905-688-3738
R23	Comp., 330 Ω, ±5%	6099-1335	75042	BTS, 330 Ω 5%	5905-686-3369
R24	Comp., 1.8 kΩ ±5%	6099-2185	75042	BTS, 1.8 kΩ ±5%	5905-688-3738
R25	Comp., 2.2 kΩ, ±5%	6099-2225	75042	BTS, 2.2 kΩ 5%	5905-723-5251
R26	Comp., 120 Ω, ±5%	6099-1125	75042	BTS, 120 Ω 5%	
R27	Comp., 300 Ω, ±5%	6099-1305	75042	BTS, 300 Ω 5%	5905-279-5481
R28	Comp., 560 Ω, ±5%	6099-1565	75042	BTS, 560 Ω 5%	
R29	Comp., 300 Ω, ±5%	6099-1305	75042	BTS, 300 Ω 5%	5905-279-5481
R30	Comp., 22 Ω, ±5%	6099-0225	75042	BTS, 22 Ω 5%	5905-755-8389
R31	Comp., 820 Ω, ±5%	6099-1825	75942	BTS, 820 Ω 5%	
R32	Comp., 100 Ω, ±5%	6099-1105	75042	BTS, 100 Ω 5%	
R33	Comp., 360 Ω, ±5%	6099-1365	75042	BTS, 360 Ω 5%	
R34	Comp., 220 Ω, ±5%	6099-1225	75042	BTS, 220 Ω 5%	5905-683-2240
R36	Comp., 1.5 kΩ, ±5%	6099-2155	75042	BTS, 1.5 kΩ 5%	
R37	Comp., 220 Ω, ±5%	6099-1225	75042	BTS, 220 Ω 5%	5905-683-2240
R38	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R39	Comp., 12 kΩ, ±5%	6099-3125	75042	BTS, 12 kΩ 5%	
R40	Comp., 2.2 kΩ, ±5%	6099-2225	75042	BTS, 2.2 kΩ 5%	5905-723-5251
TRANSFORMERS					
T1	Transformer	1682-2520	24655	1682-2520	
T2	Transformer	1682-2530	24655	1682-2530	
TRANSISTORS					
Q1	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q2	Type 2N3905	8210-1114	04713	2N3905	
Q3	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q7 and Q8	Type 2N2369	8210-1052	96214	2N2369	
Q9	Type 2N3250	8210-1089	07263	2N3250	

Figure 6-36 (S) →

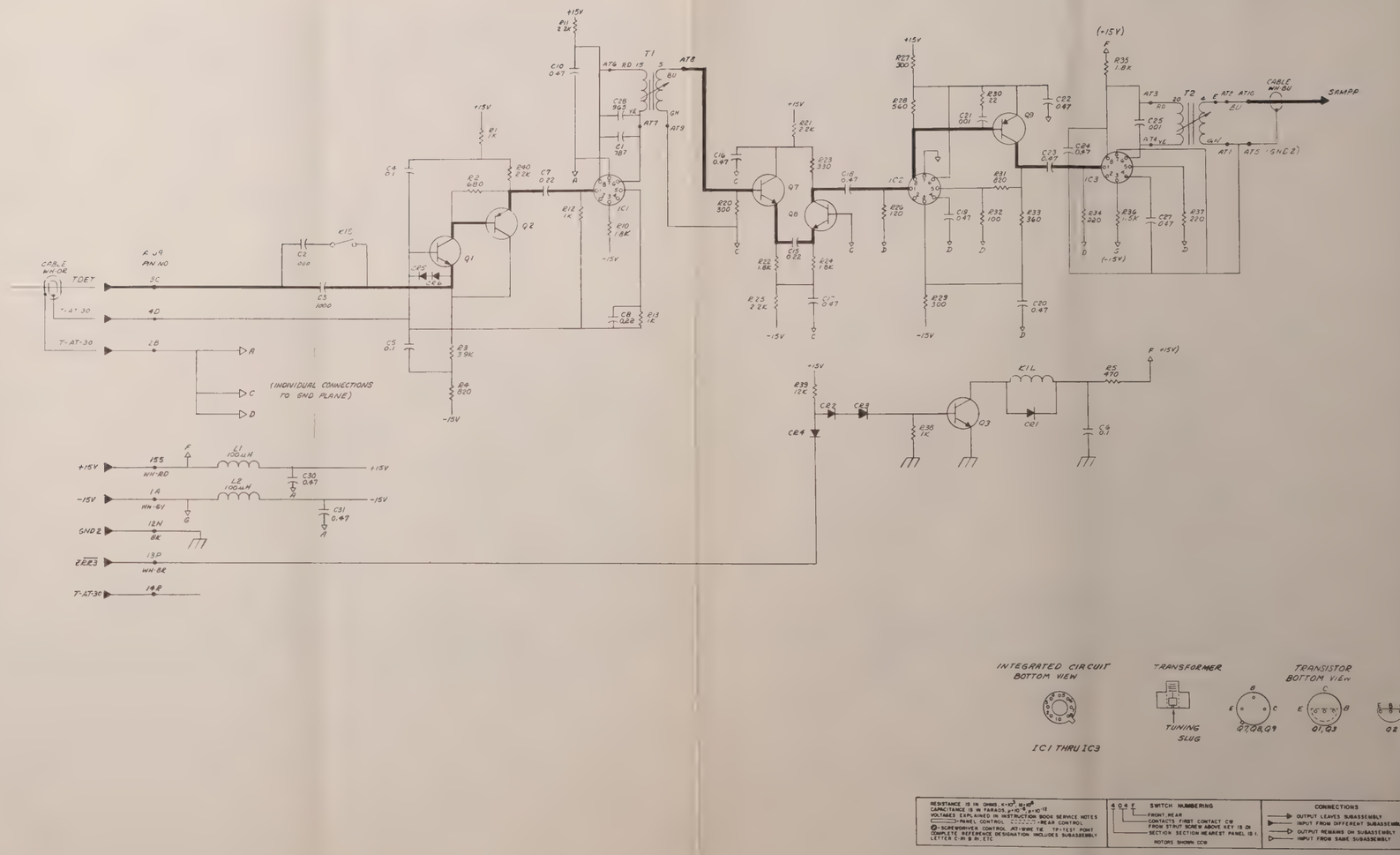
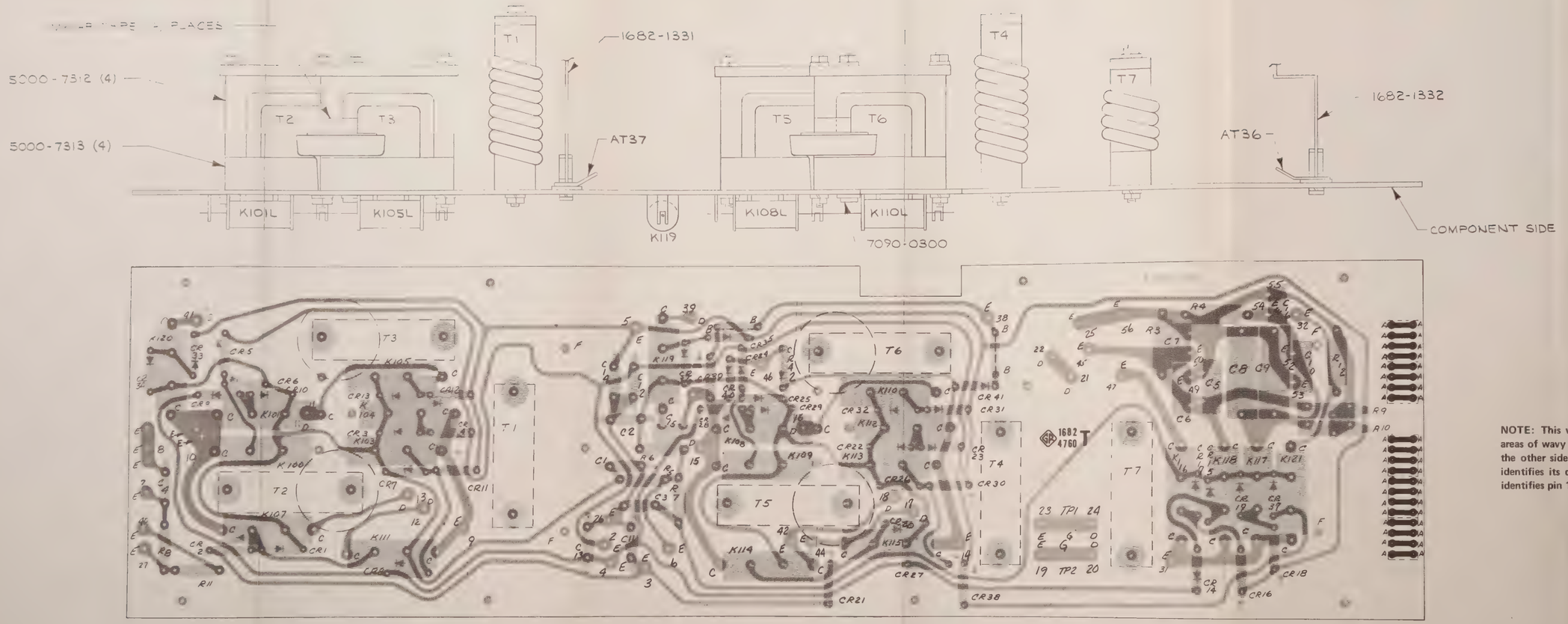


Figure 6-36. Preamplifier diagram. S



NOTE: This view is the side where parts are mounted; they are shown as areas of wavy lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

Figure 6-37. T-board assembly, showing etched circuit (P/N 1682-4760).

ELECTRICAL PARTS LIST

T BOARD

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
	COMPLETE BOARD				
T	Bridge Transformer (Note 1)	1682-4760	24655	1682-4760	
	CAPACITORS				
C1 thru C3	Ceramic, 0.1 µF	4400-2050	80183	5C13, .1 µF 20%	5910-080-4646
C4	Ceramic, .022 µF	4407-3229	72982	CC63, .022 µF +80-20%	5910-448-5383
C5	Ceramic, 499 pF 1%	4710-0570	14655	22A, 499 pF 1%	
C6 and C7	Ceramic*	4710——			
C8 and C9	Ceramic, 10,000 pF 1%	4750-0100	00656	1464, .01 µF	5910-087-7593
C10	Ceramic, 3650 pF	4590-3650	14655	5A, 3650 pF 2%	
C11 thru C14	Ceramic, 0.1 µF	4400-2050	80183	5C13, .1 µF 20%	5910-080-4646
C15	Mica, 768 pF 1%	4710-0768	14655	22A, 768 pF 1%	
C16	Ceramic*	4710——			
	DIODES				
CR1 thru CR32	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR38 thru CR39	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR42	Type 1N645	6082-1016	24446	1N645	5961-087-6047
	RELAYS				
K100L and K101L	Coil	6090-1130	71707	XU-8242-P	
K103L thru K105L	Coil	6090-1130	71707	XU-8242-P	
K107L thru K121L	Coil	6090-1130	71707	XU-8242-P	
K100S and K101S	Reed Switch	6090-1150	30874	765830	
K103S thru K105S	Reed Switch	6090-1150	30874	765830	
K107S	Reed Switch	6090-1150	30874	765830	
K108S thru K110S	Reed Switch	6090-1240	12617	MRMF-2 (Spec. F-00200)	
K111S	Reed Switch	6090-1150	30874	765830	
K112S and K113S	Reed Switch	6090-1240	12617	MRMF-2 (Spec. F-00200)	
K114S and K115	Reed Switch	6090-1260	12617	1262185130	
K116S	Reed Switch	6090-0800	30874	76586S	
K117S	Reed Switch	6090-1260	12617	1262185130	
K118S	Reed Switch	6090-0800	30874	76586S	
K119S	Reed Switch	6090-1260	12617	1262185130	
K120S and K121S	Reed Switch	6090-0800	30874	76586S	
	RESISTORS				
R3	Film, 499 Ω, ±1%	6450-0499	75042	CEC, 499 Ω 1%	5905-581-4976
R4	Film, 55.6 Ω, ±1%	6450-9556	75042	CEC, 55.6 Ω 1%	
R5 and R6	Comp., 68 Ω, ±5%	6100-0685	01121	RC20GF680J	5905-195-5571
R7	Comp., 180 Ω, ±5%	6100-1185	01121	RC20GF181J	5905-279-3514
R8	Comp., 100 kΩ, ±5%	6100-4105	01121	RC20GF104J	5905-195-6761
R9	Pot, Wire Wound, 1 kΩ, 10%	6049-0186	80294	3009D, 1 kΩ 10%	
R10	Pot., Cermet, 200 Ω 10%	6049-0184	80294	3009P, 200 Ω 10%	
R11	Comp., 100 kΩ, ±5%	6100-4105	01121	RC20GF104J	5905-195-6761
R12	Film, 4.99 kΩ, ±1%	6450-1499	75042	CEC, 4.99 kΩ 1%	
	TRANSFORMERS				
T1	Transformer asm.	1682-2910	24655	1682-2910	
T2	Dual assembly, includes T2 and T3 windings, but no cores.	1682-2900	24655	1682-2900	
T4	Transformer asm.	1682-2910	24655	1682-2910	
T5	Dual assembly, includes T5 and T6 windings, but no cores.	1682-2900	24655	1682-2900	
T7	Transformer asm.	1682-2920	24655	1682-2920	
	TRANSFORMER CORES				
	U Core for T2, 3, 5, 6	5000-7312	24655	5000-7312	
	I Core for T2, 3, 5, 6	5000-7313	24655	5000-7313	

*Value determined as required.
Note 1: This board is replaceable only by the General Radio Service Department.

Figure 6-38 (T) →

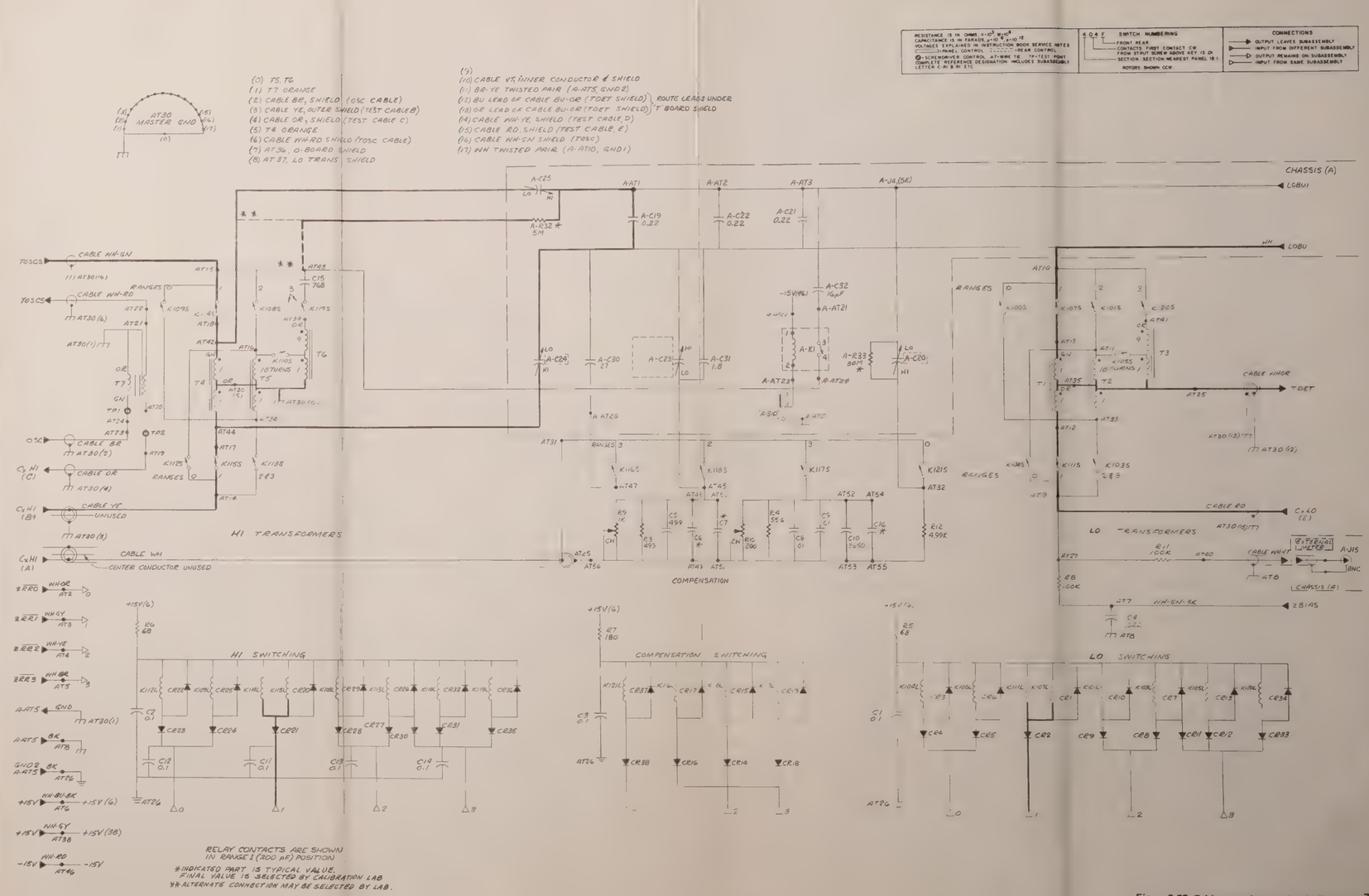

RESISTANCE IS IN OHMS, K=10³, M=10⁶
CAPACITANCE IS IN FARADS, µ=10⁻⁶, p=10⁻¹²
VOLTAGES EXPLAINED IN INSTRUCTION BOOK SERVICE NOTES
SWITCH NAME, CONTROL — REAR CONTROL
SCREWDRIVER CONTROL, AT=WIRE TIE, TP=TEST POINT
COMPLETE REFERENCE DESIGNATION INCLUDES SUBASSEMBLY LETTER C-A1 & IN ETC.
S Q A F SWITCH NUMBERING
FRONT REAR
CONTACTS FIRST CONTACT CW FROM STRUT SCREW ABOVE KEY 13 OR SECTION SECTION NEAREST PANEL 1&1
ROTORS SHOWN CCW
CONNECTIONS
OUTPUT LEAVES SUBASSEMBLY
INPUT FROM DIFFERENT SUBASSEMBLY
OUTPUT REMAINS ON SUBASSEMBLY
INPUT FROM SAME SUBASSEMBLY
(0) T5, T6
(1) T7 ORANGE
(2) CABLE BR, SHIELD (OSC CABLE)
(3) CABLE YE, OUTER SHIELD (TEST CABLE B)
(4) CABLE OR, SHIELD (TEST CABLE C)
(5) T4 ORANGE
(6) CABLE WH-RD SHIELD (TOSC CABLE)
(7) AT 36, O-BOARD SHIELD
(8) AT 37, LO TRANS. SHIELD
(9)
(10) CABLE VT, INNER CONDUCTOR & SHIELD
(11) BR-YE TWISTED PAIR (A-AT5, GND2)
(12) BU LEAD OF CABLE BU-OR (TDET SHIELD) ROUTE LEADS UNDER
(13) OR LEAD OF CABLE BU-OR (TDET SHIELD) T BOARD SHIELD
(14) CABLE WH-YE, SHIELD (TEST CABLE D)
(15) CABLE RD, SHIELD (TEST CABLE E)
(16) CABLE WH-GN SHIELD (TOSC)
(17) WH TWISTED PAIR (A-AT10, GND1)
CHASSIS (A)
LOBU1
LOBU
TOSCS
CABLE WH-GN
CABLE WH-RD
CABLE BR
CABLE OR
CABLE YE
UNUSED
CABLE WH
CENTER CONDUCTOR UNUSED
CABLE VHOR
TDET
CABLE RD
CABLE WH-VT
CABLE WH-GN-BK
HI TRANSFORMERS
LO TRANSFORMERS
COMPENSATION
HI SWITCHING
COMPENSATION SWITCHING
LO SWITCHING
RANGES
+15V(G)
-15V(G)
+15V
-15V
EXTERNAL METER
A-J15
BNC
CHASSIS (A)
RELAY CONTACTS ARE SHOWN IN RANGE 1 (100 pF) POSITION
*INDICATED PART IS TYPICAL VALUE. FINAL VALUE IS SELECTED BY CALIBRATION LAB
**ALTERNATE CONNECTION MAY BE SELECTED BY LAB.

Figure 6-38. Bridge-transformer circuit diagram. T

ELECTRICAL PARTS LIST

BOARD

Ref Des	Description	GR Part No	Fed Mfg Code	Mfg Part No.	Fed Stock No.
	COMPLETE BOARD				
V	Power-Supply Regulator	1682-4740	24655	1682-4740	
	CAPACITORS				
C1	Ceramic, 0.05 µF	4403-8500	01121	40-503W	5910-883-7321
C2	Tantalum, 47 µF	4450-5614	56289	150D476X0020R2	
C3	Ceramic, 0.05 µF	4403-8500	01121	40-503W	5910-883-7321
C4	Tantalum, 4.7 µF	4450-4700	56289	150D465X0015B2	5910-813-8160
C5	Tantalum, 47 µF	4450-5614	56289	150D476X0020R2	
C6	Ceramic, 0.05 µF	4403-8500	01121	40-503W	5910-883-7321
C7	Tantalum, 4.7 µF	4450-4700	56289	150D465X0015B2	5910-813-8160
C8	Tantalum, 47 µF	4450-5500	56289	150D476X0006B2	5910-752-4185
C9	Electrolytic, 680 µF	4450-6015	37942	TT, 680 µF, +150-10%	
	DIODES				
CR1 thru CR5	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR6	Type 1N957B	6083-1009	07910	1N957B	
CR7,CR8	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
	RESISTORS				
R1	Wire Wound, 1 Ω, ±10%	6760-9109	75042	BWH, 1 Ω 10%	
R2	Comp., 4.7 Ω, ±5%	6099-9475	75042	BTS, 4.7 Ω 5%	
R3	Comp., 3.3 kΩ, ±5%	6099-2335	75042	BTS, 3.3 kΩ 5%	5905-681-9969
R4	Comp., 360 Ω, ±5%	6099-1365	75042	BTS, 360 Ω 5%	
R5	Comp., 36 kΩ, ±5%	6099-3365	75042	BTS, 36 kΩ 5%	5905-683-7726
R6	Comp., 47 Ω, ±5%	6099-0475	75042	BTS, 47 Ω 5%	
R7	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R8	Film, 5.11 kΩ, ±1%	6350-1511	75042	CEB, 5.11 kΩ 1%	
R9	Wire Wound, 1.5 Ω, ±10%	6760-9159	75042	BWH, 1.5 Ω 10%	
R10	Comp., 4.7 Ω, ±5%	6099-9475	75042	BTS, 4.7 Ω 5%	
R11	Comp., 3.3 kΩ, ±5%	6099-2335	75042	BTS, 3.3 kΩ 5%	5905-681-9969
R12	Comp., 360 Ω, ±5%	6099-1365	75042	BTS, 360 Ω 5%	
R13	Comp., 750 Ω, ±5%	6099-1755	75042	BTS, 750 Ω 5%	
R14	Comp., 4.3 kΩ, ±5%	6099-2435	75042	BTS, 4.3 kΩ 5%	
R15	Comp., 47 Ω, ±5%	6099-0475	75042	BTS, 47 Ω 5%	
R16	Comp., 4.7 kΩ, ±5%	6099-2475	75042	BTS, 4.7 kΩ 5%	5905-686-9992
R17	Film, 4.02 kΩ, ±1%	6250-1402	75042	CEA, 4.04 kΩ 1%	5905-702-7231
R18	Pot. Wire Wound, 1 kΩ	6051-2109	02660	2600-PC, 1 kΩ 10%	
R19	Film, 3.16 kΩ, ±1%	6350-1316	75042	CEB, 3.16 kΩ 1%	5905-583-6902
R20	Film, 5.11 kΩ, ±1%	6350-1511	75042	CEB, 5.11 kΩ 1%	
R21	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R22	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R23	Comp., 3.3 kΩ, ±5%	6099-2335	75042	BTS, 3.3 kΩ 5%	5905-681-9969
R24	Comp., 4.7 Ω, ±5%	6099-9475	75042	BTS, 4.7 Ω 5%	
R25, R26	Wire Wound, 1 Ω, ±10%	6760-9109	75042	BWH, 1 Ω 10%	
R27	Comp., 360 Ω, ±5%	6099-1365	75042	BTS, 360 Ω 5%	
R28	Film, 3.01 kΩ, ±1%	6250-1301	75042	CEA, 3.01 kΩ 1%	5905-702-5974
R29	Film, 1 kΩ, ±1%	6350-1100	75042	CEB, 1 kΩ 1%	5905-892-7018
R30	Comp., 47 Ω, ±5%	6099-0475	75042	BTS, 47 Ω 5%	
R31	Comp., 11 kΩ, ±5%	6099-3115	75042	BTS, 11 kΩ 5%	
R32	Comp., 3.3 kΩ, ±5%	6099-2335	75042	BTS, 3.3 kΩ 5%	5905-681-9969
R33	Film, 4.99 kΩ, ±1%	6450-1499	75042	CEC, 4.99 kΩ 1%	
R34	Pot. Wire Wound, 500 Ω	6051-1509	02660	2600 PC, 500 Ω 10%	
R35	Film, 4.59 kΩ, ±1%	6450-1459	75042	CEC, 4.59 kΩ 1%	
R36	Comp., 56 Ω, ±5%	6120-0565	01121	RC42GF560J	5905-279-2302
R37	Comp., 620 Ω, ±5%	6099-1625	75042	BTS, 620 Ω 5%	5905-801-6998
R38	Comp., 2.7 kΩ, ±5%	6099-2275	75042	BTS, 2.7 kΩ 5%	
R39	Comp., 9.1 kΩ, ±5%	6099-2915	75042	BTS, 9.1 kΩ 5%	5905-279-4619
R40, R41	Comp., 1 kΩ, ±5%	6099-2105	75042	BTS, 1 kΩ 5%	5905-681-6422
R42	Comp., 2 kΩ, ±5%	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370
	TRANSISTORS				
Q1	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q2	Type 2N3905	8210-1114	04713	2N3905	
Q3	Type 2N1131	8210-1025	96214	2N1131	5961-081-8365
Q4	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q5	Type 2N4250	8210-1135	07263	2N4250	
Q6	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q7	Type 2N697	8210-1040	49956	2N697	5961-752-0150
Q8	Type 2N3905	8210-1114	04713	2N3905	
Q9	Type 2N3414	8210-1047	24454	2N3414	
Q10	Type 2N697	8210-1040	49956	2N697	5961-752-0150
Q11 thru Q13	Type 2N3905	8210-1114	04713	2N3905	
Q14	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q15	Type 2N3740	8210-1121	04713	2N3740	
Q16	Type 2N3905	8210-1114	04713	2N3905	
Q17	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749

NOTE: This view is the side where parts are mounted; they are outlined with fine black lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

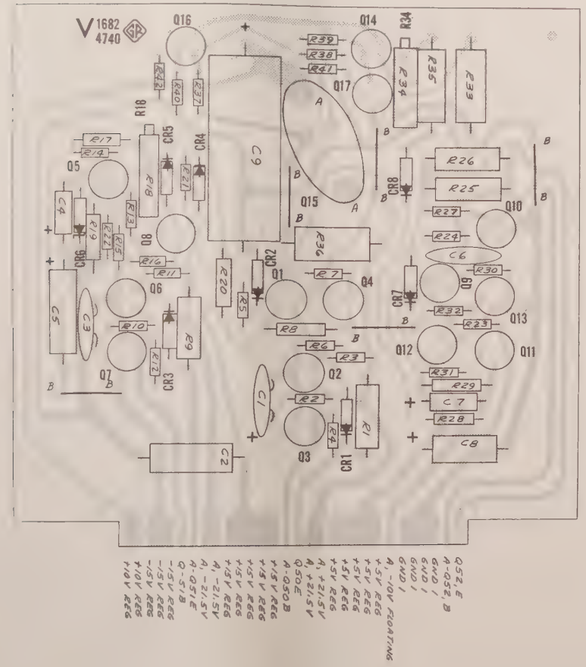


Figure 6-39. V-board assembly, showing etched circuit (P/N 1682-4740).

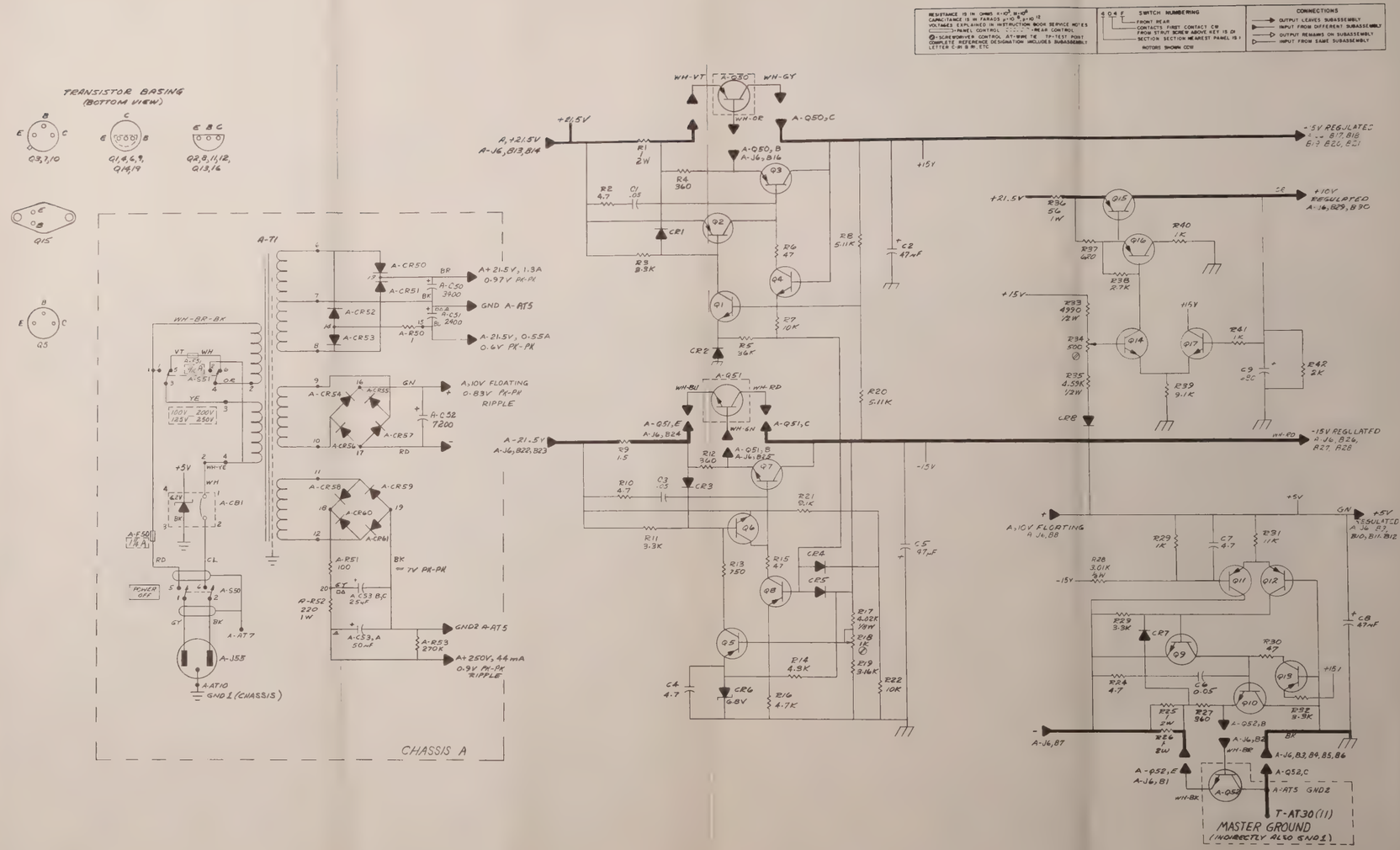


Figure 6-40. Power supply diagram. V

NOTE: This view is the side where parts are mounted; they are shown as areas of wavy lines. Etched circuitry (if any) on this side appears black; on the other side, gray. A separate dot in the etched pattern near a transistor identifies its collector; a half-moon symbol (◖) near an integrated circuit identifies pin 1. A number on the side without parts is *not* the part number.

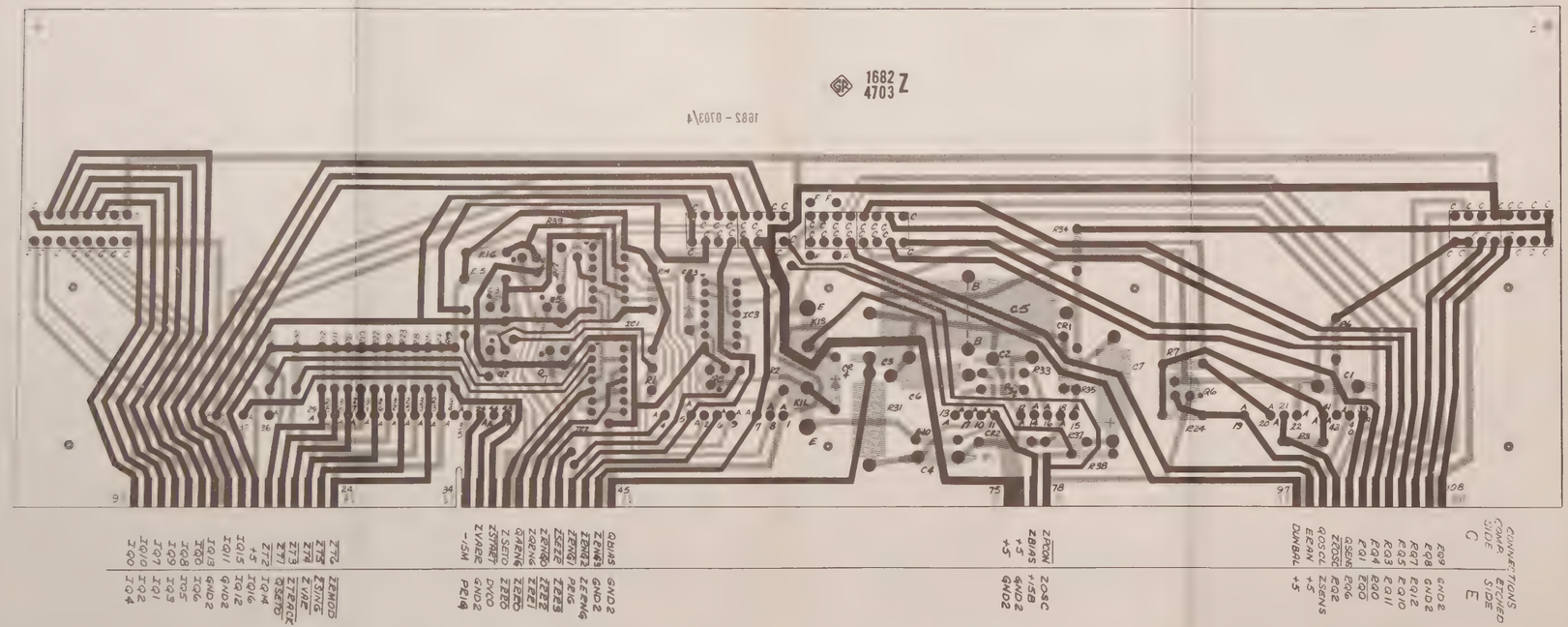


Figure 6-41. Z-board assembly, showing etched circuit but not front-panel controls (P/N 1682-4703).

ELECTRICAL PARTS LIST

Z BOARD AND ASSEMBLY

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
CONTROL PANEL ASSEMBLY					
	Panel with components and knobs, wired to Z board, with H board, tubes, and indicator assemblies.	1682-2100	24655	1682-2100	
COMPLETE BOARD					
Z	Manual Control.	1682-4703	24655	1682-4703	
CAPACITORS					
C1	Ceramic, 0.1 μF +80-20%	4403-4100	80131	CC63, .1 μF +80-20%	5910-974-5699
C2 thru C4	Ceramic, .022 μF +80-20%	4407-3229	72982	CC63, .022 μF +80-20%	5910-448-5383
C5	Electrolytic, 10 μF	4450-2100	37942	97681	5910-318-6508
C6	Electrolytic, 18 μF	4450-5230	56289	150D186X001B2	
C7	Electrolytic, 10 μF	4450-3800	56289	30D106G025BB4M1	5910-852-8658
INTEGRATED CIRCUITS					
IC1	Digital	5431-9362	96214	SN15836N	
IC2 and IC3	Digital	5431-9462	96214	SN15846N	
DIODES					
CR1	Type 1N985B	6083-1043	93916	1N985B	5960-813-9009
CR2	Type 1N758A	6083-1012	07910	1N758A	
CR3	Type 1N3604	6082-1001	24446	1N3604	5961-995-2199
CR4	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
RELAYS					
K1L	Coil	6090-1130	71707	XU-8242-P	
K1S	Switch	6090-0800	30874	76586S	
RESISTORS					
R1 thru R5	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R6	Comp., 15 Ω, ±5%	6099-0155	75042	BTS, 15 Ω 5%	
R7 thru R12	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R14 thru R17	Comp., 1.5 kΩ, ±5%	6099-2155	75042	BTS, 1.5 kΩ 5%	
R19 thru R24	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R30	Comp., 5.6 kΩ, ±5%	6099-2565	75042	BTS, 5.6 kΩ 5%	5905-691-0195
R31	Comp., 10 kΩ, ±5%	6120-3105	01121	RC42GF103J	5905-185-8516
R32	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R33	Comp., 10 kΩ, ±5%	6099-3105	75042	BTS, 10 kΩ 5%	5905-683-2238
R34 and R35	Comp., 24 kΩ, ±5%	6099-3245	75042	BTS, 24 kΩ 5%	
R37 and R38	Comp., 82 Ω, ±5%	6099-0825	75042	BTS, 82 Ω 5%	
R39	Comp., 1.5 kΩ, ±5%	6099-2155	75042	BTS, 1.5 kΩ 5%	
R40	Comp., 47 Ω, ±5%	6099-0475	75042	BTS, 47 Ω 5%	
TRANSISTORS					
Q2 thru Q8	Type 2N3414	8210-1047	24446	2N3414	5961-989-2749

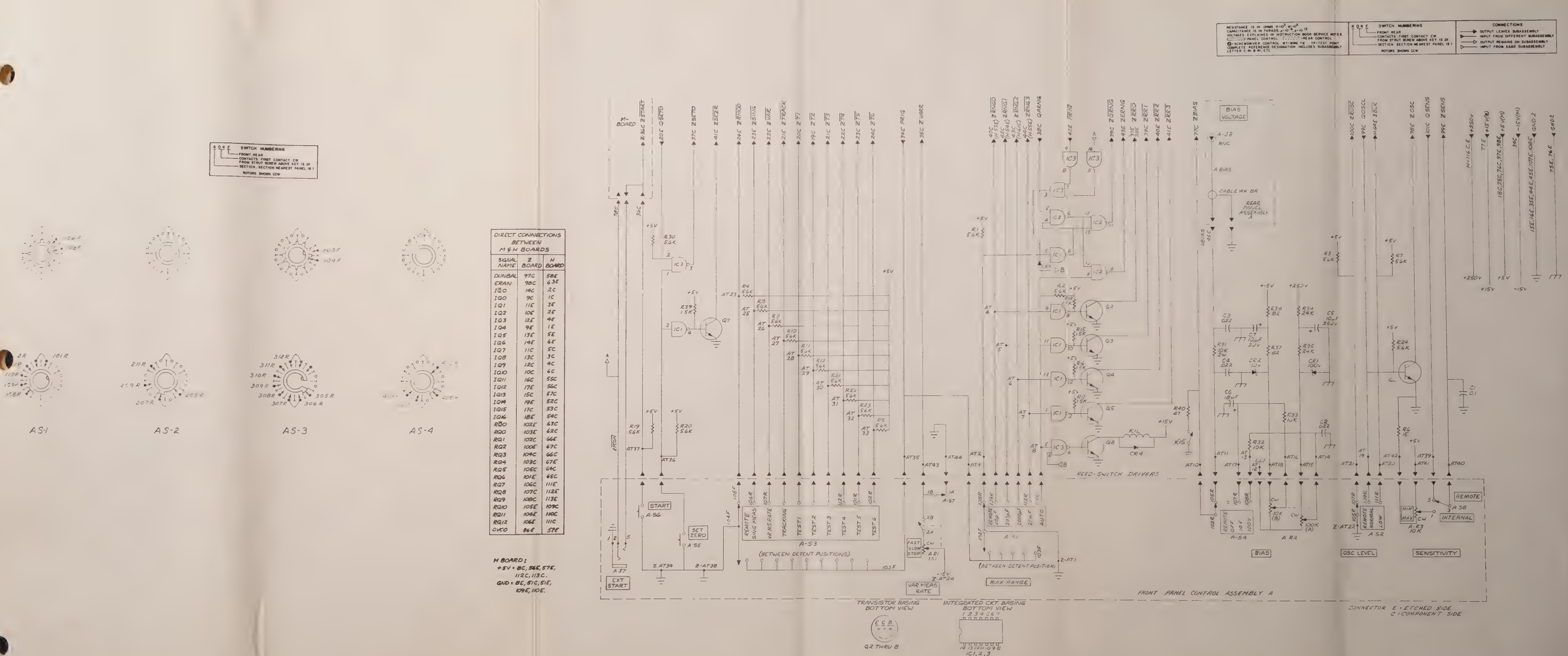


Figure 6-42 (Z) →

Figure 6-42. Manual control circuit diagram. Z

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